Duplex Telegraphy

By

DONALD McNICOL, Fellow A. I. E. E.

COMMUNICATION ENGINEER

DUPLEX AND QUADRUPLEX TELEGRAPHY

Parts 1–2

DUPLEX REPEATERS

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Note.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

DUPLEX TELEGRAPHY, PART 1

DUPLEX TELEGRAPHY, PART 2

DUPLEX REPEATERS

DUPLEX TELEGRAPHY

(PART 1)

Serial 1504A — Edition 2

DIFFERENTIAL DUPLEX SYSTEM

INTRODUCTION

1. Definition of Terms.—Methods of transmitting single messages over a line are frequently called **simplex** to distinguish them from those systems, known as **multiplex**, by which two or more messages are transmitted over a wire at the same time. The advantage of the multiplex system lies in the fact that as one line can do the work of two or more lines, the expense of erecting and maintaining the other lines is saved. A good ground return, though, is necessary for the successful working of this system. Multiplex systems for sending two messages simultaneously in opposite directions over one wire are termed **duplex systems.** Sometimes these systems are termed **contraplex telegraphy**, to imply that the messages are being sent in contrary or opposite directions. On a duplex system there is one sending and one receiving operator at each end or office, that is four operators in all. There are three systems of duplex telegraphy: the *differential*, *polar*, and *bridge*.

The transmission of two telegraphic messages simultaneously in the same direction over the same wire is called the **diplex system**; this term is the opposite of contraplex. On a diplex system there are two sending operators at one end and two receiving operators at the other end, or four operators in all.

The simultaneous transmission of four independent messages, two in one direction and two in the other, is termed the **quadruplex system.** This system requires two sending and two receiving operators at each end, eight operators in all.

2. Method of Indicating Various Circuits.—Whenever it is not especially inconvenient or confusing to do so, the following system of drawing in the various circuits in the diagrams for multiplex systems will be used: The main-line circuit will be drawn in full lines; the artificial-line circuit, in two dots and one dash; the local receiving circuit, in dots; the local sending circuit, in dashes; and the balancing ground-coil

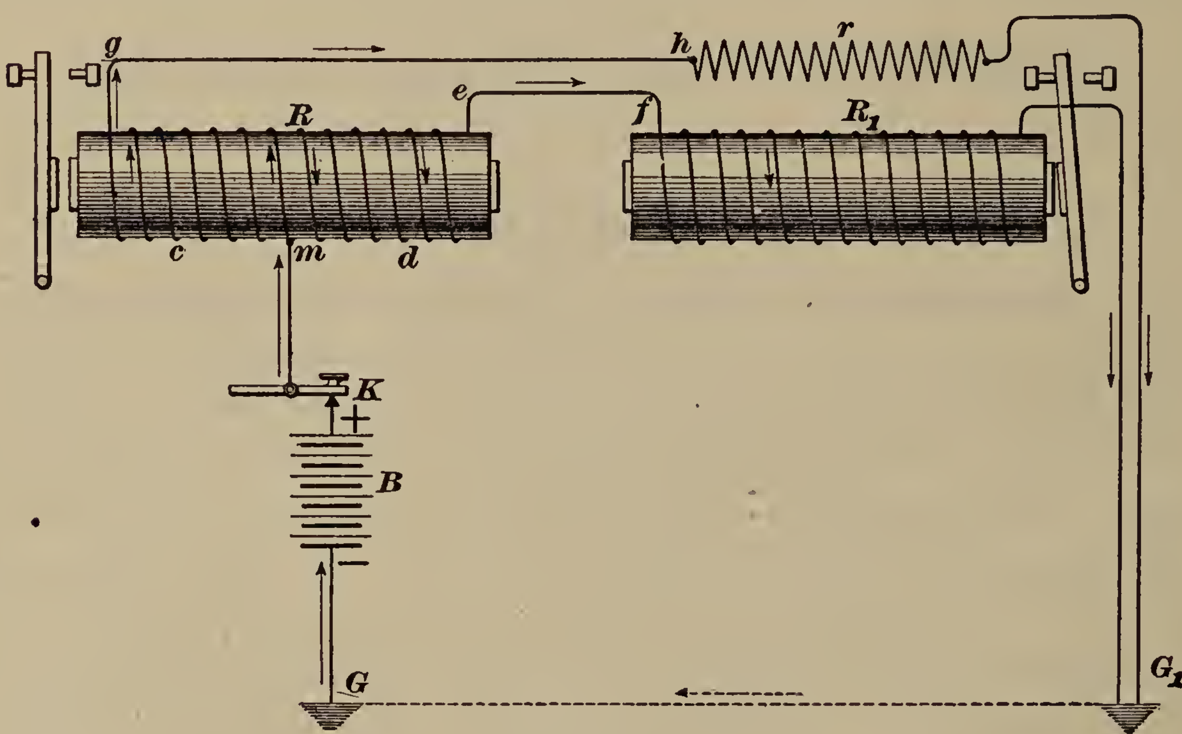


FIG. 1

circuit in the polar, duplex, and quadruplex systems, in one dot and one dash. This plan will make it possible for one to readily distinguish and trace out the various circuits.

PRINCIPLES OF OPERATION

3. Neutral Relay.—The essential feature of the **differential duplex system,** which is also known as the **Stearns duplex,** is the differentially wound relay. In the case shown in Fig. 1, the two outside ends of the differential relay *R* are extended to a distant station through two line wires *g h* and *e f*.

A relay R_1 is connected in one line $e\,f$ and a resistance r equal to the resistance of this relay R_1 is connected in the other. Both circuits are grounded at G_1.

The winding on the differential relay R is divided into two parts, c and d, which have an equal number of turns and an equal resistance, by a connection made at its middle point m. As the two line wires $e\,f$ and $g\,h$ have equal resistances and equal electrostatic capacities, the resistance and electrostatic capacity from the middle point m through $d-e-f-R_1-G_1$, is equal to that through $c-g-h-r-G_1$. Therefore, when the key K is closed, the current will divide equally at m, one-half flowing to G_1 through each of the two circuits, and the relay core R will not be magnetized because two equal currents flow around it in opposite directions. The magnetizing effect of one coil is completely neutralized by that of the other coil. Such a differentially wound nonpolarized relay is commonly called a **neutral relay.**

4. Not only will the steady or final current strength in both coils be the same, but as the capacities and the resistances in the two circuits are equal, the currents in both coils of the neutral relay will rise and fall at exactly the same rate. If the current should reach its maximum value or fall from its maximum value to zero much quicker in one coil than in the other, the armature of the relay would be momentarily affected every time the home key was closed or opened. By the arrangement shown in Fig. 1, however, the home relay R is not affected by the operation of the home key K. This is one of the conditions that must be fulfilled in any successful duplex system. At the distant end, the current that flows over the line $e\,f$ will flow through the relay R_1, and, consequently, that relay will respond every time the key K at the other end is closed, provided, of course, that the current has sufficient strength.

5. The Condenser.—Instead of extending the end of the coil c through the line $g\,h$ and the resistance r to the ground G_1 at the distant end, let it be grounded at G at the home station, as shown in Fig. 2, and include between g and G a resistance r equal to the resistance from e through the line $e\,f$ and the coil d, to the ground G_1, also a condenser C having a capacity equal to that of the line ef and so arranged that it will charge and discharge at the same rate as the line. Then the opening and closing of the home key K will have no effect on the home relay R, but it will operate the distant relay R_1. The condenser C is a very necessary part of this equipment. For if no condenser is used, the current will rise to its maximum value in one coil of the home relay R before it does in the other, causing a movement, or momentary *kick*, as it is called, of the armature every time the home key K is opened or closed. This kick of the armature would cause *false signals* every time the home key was operated and would seriously interfere with incoming signals and render the method useless, except, perhaps, on very short lines.

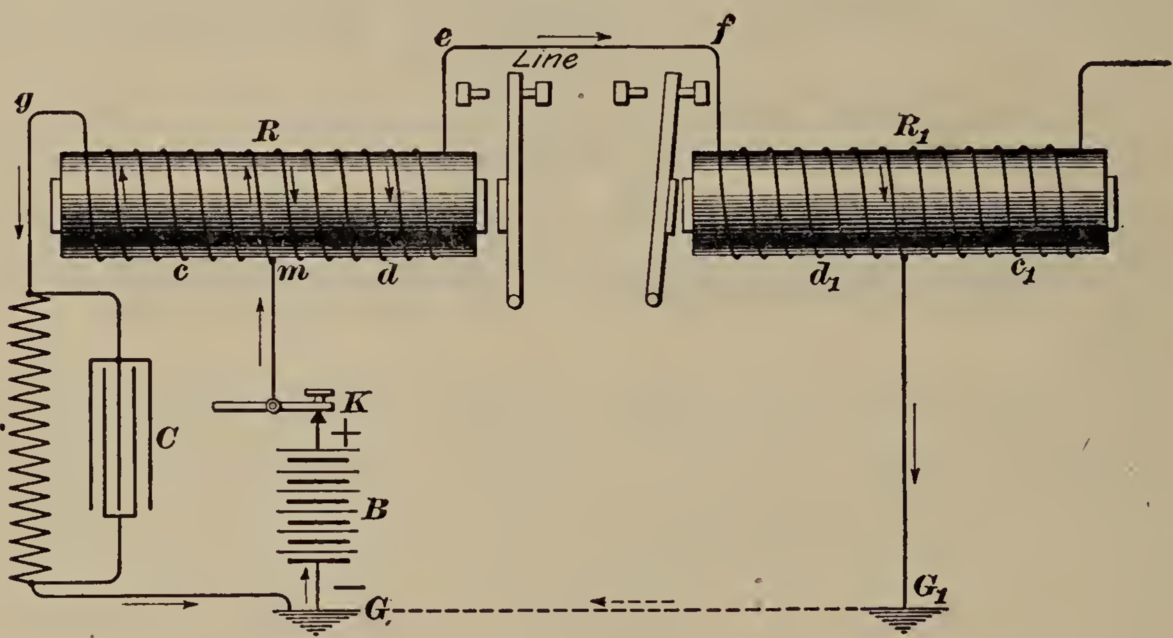


FIG. 2

The application of the condenser to the artificial line in order to give it a capacity equivalent to that of the line, was first made, in 1872, by Stearns, who was a pioneer inventor in duplex telegraph work. Without this discovery the duplex and quadruplex systems at present in use would not be practicable.

6. The capacity of the condenser C should be arranged to resemble the distributed capacity of the line wire. A simple condenser will charge and discharge more quickly than a line wire, in which the capacity is distributed throughout its length. The longer the line and the larger its capacity, the more care must be taken to make the artificial line resemble it. The way in which this is accomplished will be explained in connection with the practical arrangement of the various systems.

7. Artificial Lines and Line Coils.—In order to transmit messages in both directions simultaneously, the arrangement of apparatus at each end must be similar, as shown in Fig. 3. The keys K, K_1 have rear and front contacts and, normally, the levers of the keys rest on the rear contacts a, a_1, which are connected to the ground. Thus the key arrangement resembles that used on the Morse open-circuit system. The resistance

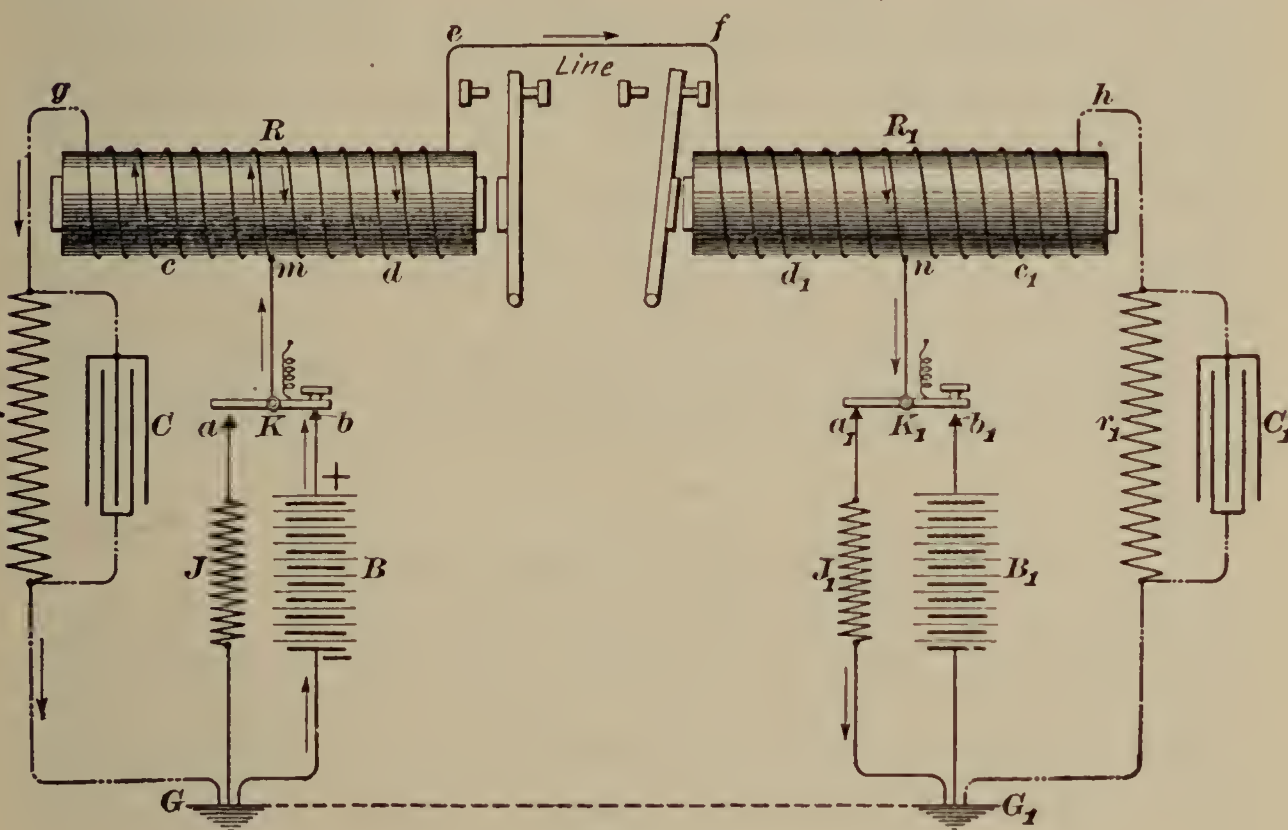


Fig. 3

and capacity of the circuit from the middle m of the home relay R through the coil c and the resistance r and condenser C to ground G should be equivalent to the resistance and capacity of the circuit from m through $d-e-f-d_1-n-a_1-J_1-G_1$. Similarly, the resistance and capacity of the circuit from the middle n of the distant relay R_1 through the coil c_1 and the resistance r_1 and condenser C_1 to ground G_1 should be equivalent to that of the circuit from n through $d_1-f-e-d-m-a-J-G$. The circuit from the end g of the home relay R to the ground G, containing the resistance r and the condenser C, and the circuit from the end h of the distant relay R_1 to the ground G_1, containing the resistance r_1 and the condenser C_1, are called the **artificial lines.** The coils c and c_1 are called the **artificial-line coils** and the coils d and d_1, the **line coils** of the relays.

8. Battery Resistance.—A resistance J, Fig. 3, equal to the internal resistance of the battery B must be inserted between the ground plate G and the rear contact a of the key K. This will give a path of equal resistance from m to the ground G, whether the key K rests on the front or rear contact; J_1 is a similar resistance, equal to the internal resistance of the battery B_1. If such resistances are not used, the home relay R, assuming the distant key K_1 to be closed, will be more strongly magnetized when the home key K is open than when closed, because the current through the line coil d of the home relay R will be greater when the home key K is open than will be the current through the artificial-line coil c when the home key K is closed. The unequal magnetization of the relay would produce an inequality in the signals that it is very desirable to avoid.

POSITIONS OF TWO KEYS

9. When messages are being transmitted simultaneously in both directions, the two keys may be in such positions as to form any one of the following four combinations: Both keys may rest on their rear contacts, both may be on the front contacts, the home K may be on the rear and the distant K_1 on the front contact, and vice versa. No matter which position the home key K occupies, the operation of the distant key K_1 will not affect the distant relay R_1 but it will operate the home relay R. Similarly, no matter which position the key K_1 occupies, the operation of the other key K will not affect its home relay R but will operate the distant relay R_1.

10. One Key Closed.—Suppose that one key K_1 rests on the back contact a_1 and that the other key K is pressed against the front contact b, or **closed,** as it is called. Current then flows from the positive pole of the battery B, charging both the line and the condenser C. When it reaches its maximum value, it flows steadily through the contact b to the middle point m of the relay R, where it divides equally, one half flowing through the artificial-line coil c and the artificial-line resistance r back to the battery B. The other half flows through $d-e-f-d_1-n-a_1-J_1-G_1$ to the ground plate G, and back to the battery B. There is also a closed circuit from the middle point n of the relay R_1 through the artificial-line coil c_1 and the artificial-line resistance r_1 to the ground plate G_1; but the resistance of this path is so very large, compared to that of the path through a_1 and J_1 to G_1, that it need hardly be considered. Moreover, even if there is an appreciable current in the artificial-line coil c_1, it flows in the proper direction in this case to help, and not to oppose, the magnetizing influence of the current through the line coil d_1. Thus the closing of the home key K will not magnetize, temporarily or permanently, the home relay R, because the currents through the two coils c and d are equal and circulate in opposite directions around the iron core of the relay, producing, therefore, no resultant magnetizing force. However, the distant relay R_1 is magnetized because the currents through the two coils c_1 and d_1 are not equal and opposite in direction, and, furthermore, the current in the coil d_1 is strong enough to cause the armature to be attracted. Hence, the home relay R is not magnetized, but the distant relay R_1 is magnetized when the home battery B is connected in the circuit by closing the home key K. In like manner, when the distant key K_1 is closed only the home relay R is affected.

11. Both Keys Closed.—If, while the home key K is against the front contact b, the distant key K_1 is closed, the batteries B and B_1 will be in opposition in the circuit $B-b-K-m-d-e-f-d_1-n-K_1-b_1-B_1-G_1-G-B$. These two batteries contain the same number of cells and have the same electromotive force; consequently, in the circuit just traced, the current will be zero, as the electromotive forces of the batteries are opposed to one another. With both keys closed, the currents in the artificial-line circuits, that is, in $B-b-K-m-c-g-r-G-B$ and in $B_1-b_1-K_1-n-c_1-h-r_1-G_1-B_1$, are due to the electromotive force of only one battery in each circuit; hence, these currents will have their normal strength. Consequently, while there is no current in the line coils d and d_1, there is sufficient current in the artificial-line coils c and c_1 to magnetize both relays R and R_1; therefore, when both keys are closed at the same time, both relays will be closed. Although current from the home battery B closes the home relay R, it is the distant key K_1 that controls the opening and closing of the home relay R. The home key K has no control over the home relay R.

As it has been shown that the distant relay R_1 is energized and the home relay R unaffected when only the home key K

TABLE I

COMBINATIONS OF KEY-AND-RELAY POSITIONS

West Key K	East Key K_1	Western Office				Eastern Office			
		Current in		Difference	Relay R	Current in		Difference	Relay R_1
		Coil d	Coil c			Coil d_1	Coil c_1		
Open	Open	0	0	0	Open	0	0	0	Open
Closed	Open	+1	+1	0	Open	−1	0	1	Closed
Open	Closed	−1	0	1	Closed	+1	+1	0	Open
Closed	Closed	0	+1	1	Closed	0	+1	1	Closed

is closed, and that both relays are energized when both keys are closed, it follows that the relay R is energized and R_1 unaffected when only K_1 is closed, and that neither relay is magnetized when both keys are open, because both batteries are then cut off.

12. Key-and-Relay Positions.—Let us consider that whenever a current flows from the home key through the two coils on the home relay toward the line and artificial line, respectively, it is a positive current; and, conversely, that whenever the current flows from the line or artificial line through the coils of the home relay toward the key, it is a negative current. Furthermore, let the current flowing through one artificial-line circuit that is due to one battery be considered as having a strength of 1 unit. Then the four possible combinations of key and relay positions and the currents in each coil may be summarized as shown in Table I. It will be noticed that whenever the difference between the currents in the two coils of one relay is not zero, the relay is closed and, furthermore, that the distant relay is open or closed corresponding to whether the home key is open or closed.

13. Cause and Prevention of False Signals.—If, at the same moment, both keys should be in an intermediate position, touching neither the front nor the rear contact, there would be no current in any of the relay coils. Consequently, both relays would open every time this occurred, causing false signals and confusion, if means were not taken to prevent them. When gravity cells are used, false signals may be easily avoided by using a continuity-preserving transmitter that is so constructed that when it is moved, contact is made with one stop before the contact with the other stop is broken. A continuity-preserving transmitter that is much used in repeaters and in duplex and quadruplex systems was described in connection with telegraph repeaters. Where dynamos that furnish current at a high potential are used, such a transmitter is not very satisfactory, on account of the injurious sparking that occurs every time the transmitter opens the short circuit it has made around the dynamo.

If the transmitter used does not perfectly preserve the continuity of the circuit, the false signals may be avoided by connecting a repeating sounder in a circuit through the back stop of the differential relay, and an ordinary sounder in another circuit through the back stop of the repeating sounder. This arrangement will give the signals properly, provided the interval of no current in the relay, although long enough to allow its armature to break contact with the regular front stop, is still too short to allow the armature to cross the gap and make contact with the back stop; for the circuit of the second sounder is not closed until the armature of the repeating sounder touches its own back stop. This arrangement, which was first devised by Edison, is successfully used on the neutral-relay side of some quadruplex systems, in connection with which it will be more fully explained.

PRACTICAL ARRANGEMENT

14. The practical arrangement of the Stearns, or differential, duplex is shown in Fig. 4. The arrangement at the two ends is slightly different in order to show both in one figure. R and R_1 are the differential relays; S and S_1, the local sounders; T and T_1, continuity-preserving transmitters; and K and K_1, ordinary telegraph keys connected in local circuits with batteries and the magnet coils of the transmitters. By using the ordinary key and a transmitter connected as shown, operators can send better and faster than by using a double-contact key as is shown in Fig. 3. In all multiplex systems where manual transmission is employed, except perhaps on cables, an ordinary key connected in a local circuit is used to control some form of a transmitter or pole changer. The circuit containing the transmitter, or pole-changer magnet, and the telegraph key is called the **sending circuit,** the **sending side,** or the **sending leg** when it is extended to a branch office. The resistance of the transmitter magnet is usually about the same as the sounder magnet, and the local transmitter circuits are supplied with current in the same manner as are the sounders.

15. The diagram is drawn to show the condition of affairs when both keys K and K_1 are closed, causing both relays R and R_1 and both sounders S and S_1 to be closed. The arrows represent the direction and the figures on the arrows the relative magnitude of the currents in the various parts of the circuit. Practically, it makes no difference which pole of the main-line battery is connected to the home ground. The positive of one and the negative of the other main-line battery may be connected to the ground, or the positive or negative terminals, as shown in Fig. 3, of both batteries may be grounded.

16. Adjusting Artificial Line.—The rheostats Rh and Rh_1, Fig. 4, usually contain between 6,000 and 7,000 ohms and

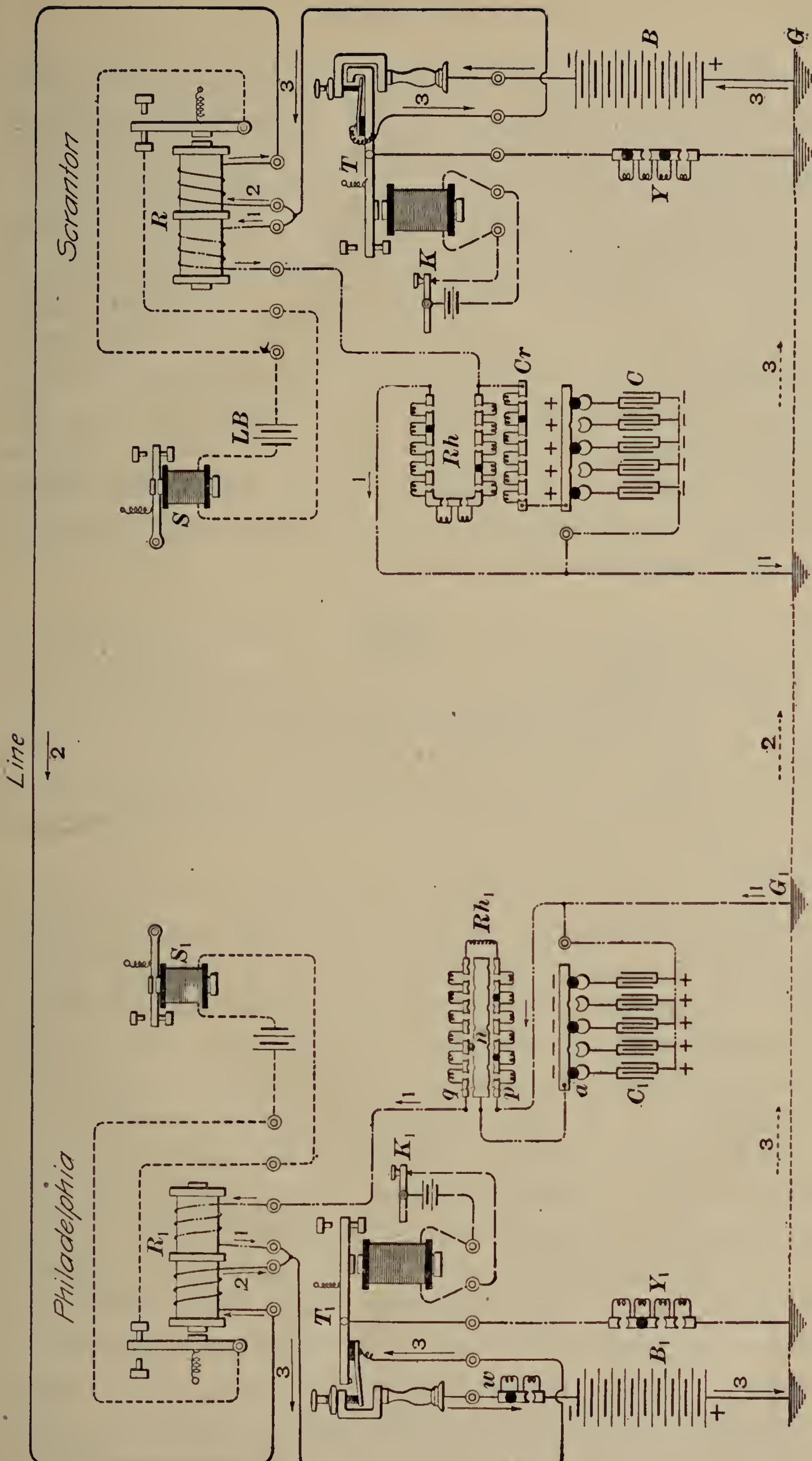

Scranton
Philadelphia
Line
R
S
LB
T
K
B
G
Y
Cr
Rh
C
R_1
S_1
T_1
K_1
Rh_1
C_1
B_1
Y_1
G_1
w
q
p
a

FIG. 4

are adjustable by steps of 100 ohms or less, thus permitting them to be used on lines of No. 6 B. W. G. iron wire that do not exceed about 600 miles in length. For a No. 6 B. W. G. line wire 600 miles long, as much as 9 microfarads may be required in the condenser C. At the Scranton end, an adjustable resistance Cr, called a *retarding coil*, is placed in series with the condenser in order that the artificial line may be made to charge and discharge as slowly as does the line. If the condenser discharged before the line, although the total discharge may be exactly the same, there would be a false signal due to the inequality in the rate of discharge of the two circuits. To avoid making this false signal the artificial line must be arranged and adjusted to charge and discharge at exactly the same rate as does the line, neither faster nor slower.

17. At the Philadelphia end, the condenser and resistances are arranged without this coil, but there the adjustable rheostat Rh_1 has a brass center strip n to which one terminal of the condenser is joined. In this case a plug may be placed, as shown at n, so as to connect one terminal of the condenser to any coil in the rheostat and thus control the rate and total discharge of the condenser through the relay.

When a current of electricity is flowing through a wire, the difference of potential between two points that are near together is less than that between the points that are farther apart. Hence, as the charge that a condenser receives depends on the difference of potential at its terminals, the charge that the condenser C_1 will take may be regulated by connecting the terminal a of the condenser to different coils of the rheostat Rh_1. At the Philadelphia end, in Fig. 4, this terminal is shown connected to a coil through the plug at n. The nearer this connection is made to the line, the greater will be the resistance between the terminals of the condenser; and, hence, the greater will be the charge taken by the condenser. The nearer it is made to the ground, the less will be the charge taken by the condenser. If the plug is placed in the hole q, the condenser receives the largest charge possible in this arrangement, while if the plug is placed in the hole p, the condenser will receive no charge, as both terminals of the condenser are, practically, connected together. Thus, by adjusting the number and position of the plugs along *a* and the position of the plug *n*, and, further, by adjusting the total amount of resistance in the rheostat Rh_1, this artificial line may be adjusted to charge and discharge at exactly the same rate as the line and, furthermore, to have the same total resistance and capacity.

18. Spark Coil.—The resistance *Y*, Fig. 4, which corresponds to *J* in Fig. 3, is adjusted to equal the internal resistance of the battery *B*, so that the resistance from the tongue of the transmitter to the ground at the same station will be the same in both the open and closed positions of the transmitter. This is the purpose for which the resistance *Y* is used, but it is usually

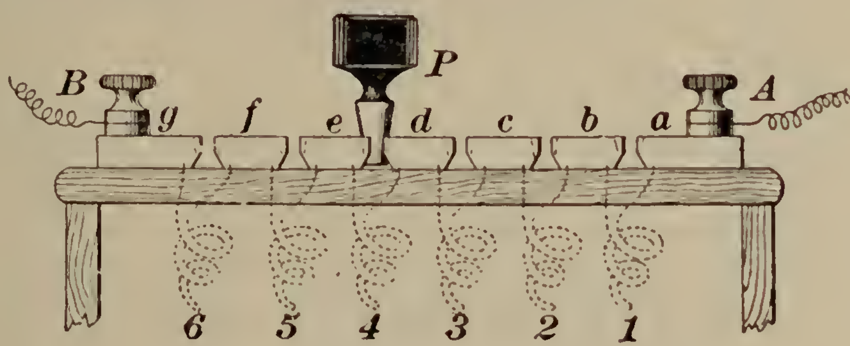


Fig. 5

called the **spark coil** because it also diminishes the intensity or quantity of current in the spark when the short circuit around the battery is broken at the continuity-preserving transmitter *T*. The resistance *w* is necessary when low internal-resistance batteries or dynamos are used in place of the battery B_1, in order to prevent too large a current from flowing, especially in case of a short circuit, and injuring the dynamo or contact points of the transmitter. In case such a resistance *w* is used, the resistance Y_1 of the balancing ground-coil circuit must be equal to that of *w* plus the internal resistance of the battery B_1. In this arrangement *w* is sometimes called the spark coil, or the *protective resistance*, and Y_1 the **ground coil.**

19. Adjustable rheostats are made in various forms. In Fig. 5 is shown the construction and arrangement of the coils in one form of rheostat in which the adjustment is made by means of brass plugs, or pegs. The coils are wound back upon themselves on wooden spools so they shall have no inductance. When wound in this manner, they are called **non-inductive resistance coils.** If they were wound continuously around the spool in one direction, like an ordinary relay coil, their inductance would often be a very serious and annoying factor. It will be evident that the insertion of the plug *P* in the hole between the brass blocks *e* and *d* short-circuits the fourth coil, or "cuts it out" as it is frequently expressed. Thus, by the use of enough plugs, any number of coils may be cut out, thereby reducing the resistance as much as may be desired. The blocks are usually mounted on hard rubber and the resistance of each coil in ohms is usually stamped on the cover opposite the hole,

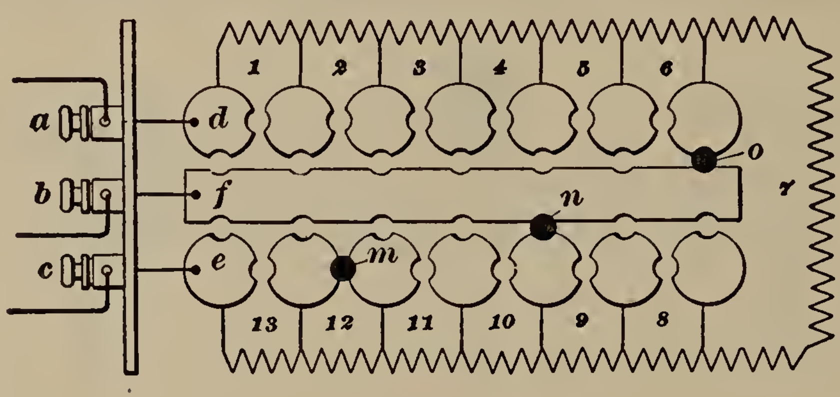


FIG. 6

or on the adjacent brass block or disk. Fig. 5 shows only one row of coils, but the boxes frequently contain several rows.

20. In Fig. 6 is shown the top of a very convenient form of adjustable rheostat for use in artificial-line circuits. Between the two binding posts *a* and *c*, when all plugs are removed, there will be the resistance of the thirteen coils in series; that is, the sum of all the coils whose values are stamped on the brass disks or on the ebonite cover opposite the holes. If a plug is inserted at *m*, for instance, coil *12* is cut out. If a plug is inserted at *o* and another at *n*, the intervening coils *7*, *8*, and *9* are cut out. Where this box is used on duplex and quadruplex systems, the middle brass strip *f* is connected through the middle binding post *b* to a condenser. By means of a plug, the strip *f* and, hence, one terminal of the condenser may be connected to any coil in the rheostat. In such a case, *f* would usually be connected to one disk and coil by plugging only one hole, the resistance being adjusted by plugging between disks.

21. Adjustable Condenser.—One form of adjustable condenser used in connection with various telegraph systems is shown in Fig. 7. The total capacity is divided into five sections; the capacity of the first section is 4 per cent. of the total capacity. The percentage capacity of each section is plainly marked on the disk to which the section is joined. If the total capacity of the condenser is 2.5 microfarads, then, by placing a plug in the hole *b*, Fig. 7 (*n*), the capacity of the condenser

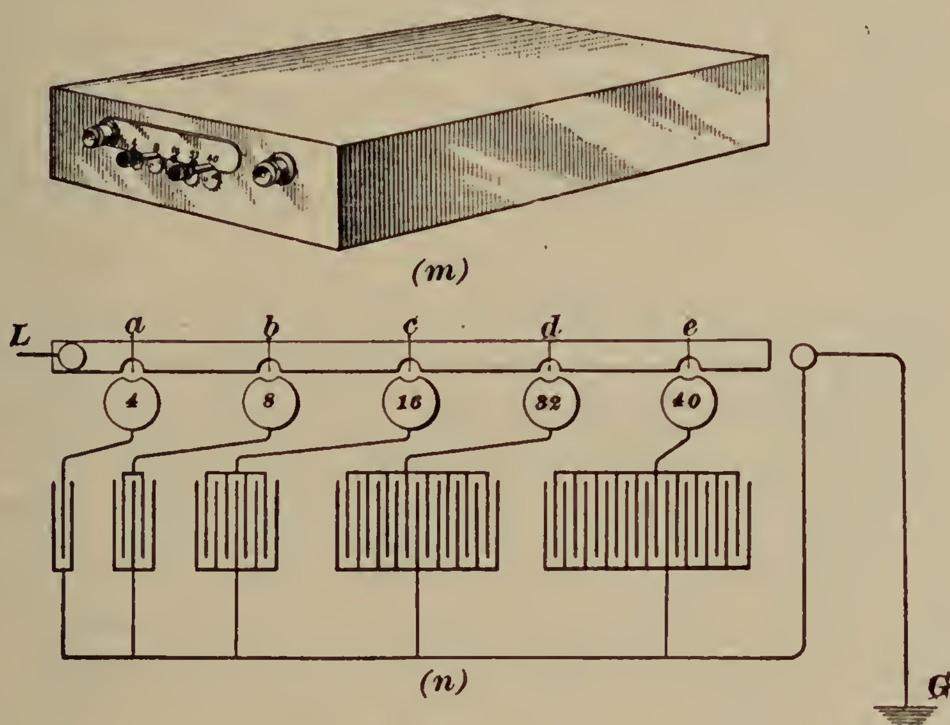


Fig. 7

between *L* and the ground *G* will be 8 per cent. of 2.5; that is, .2 microfarad. By placing plugs in the holes *a*, *c*, and *d*, the capacity will be 4+16+32=52 per cent. of 2.5, that is, 1.3 microfarads. The condenser can be adjusted by steps of .1 microfarad from .1 up to 2.5 microfarads. The finished appearance of the condenser is shown at (*m*). Sometimes the actual capacity of each section is marked on the disk to which it is connected.

22. Differentially Wound Neutral Relays.—Neutral and polarized relays may be differentially wound in several ways. The idea to be kept in mind is to so arrange the two coils that the resistance and the number of turns in each winding will be exactly equal, and the effect of equal currents in each coil on the movable part of the relay will be the same in intensity. The best way would be to wind the coils with two wires, side by side, as shown in Fig. 8 (*a*). Then the two wires, being insulated from each other, would form two coils as nearly alike in every way as it is possible to get them. The wires composing the two windings on each core, being side by side, would cause the differential action to be, largely, between currents in the windings rather than between magnetisms produced in the cores by such currents. But this is not a con-

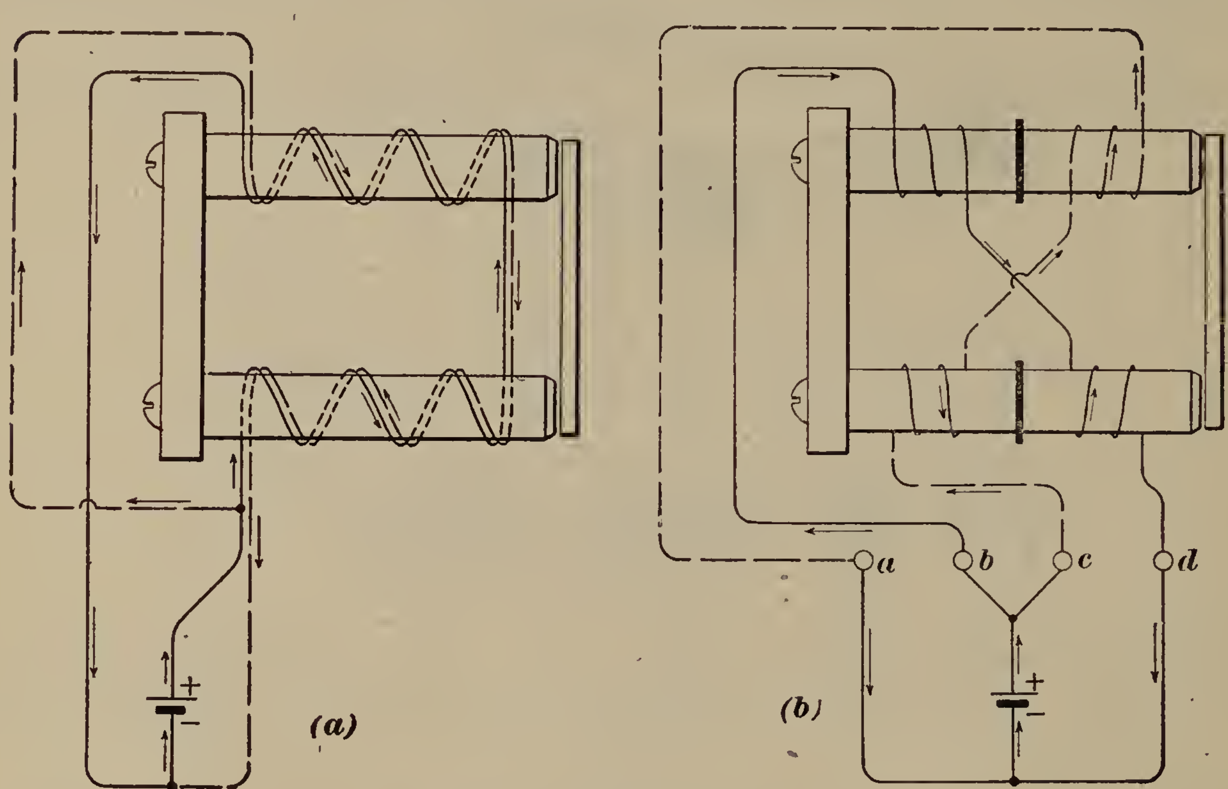


FIG. 8

venient nor a profitable way to wind them. The other extreme is to wind one coil on each core of the magnet. This is not a good way, because, although the two coils may be very much alike, they would not neutralize each other very well. A compromise that has proved satisfactory consists in winding four coils, two on each core, the rear coil on one core, together with the forward coil on the other core, forming one half of the differential winding, and the forward coil on the first core, together with the rear coil on the second core, forming the other half. This method of winding is shown in Fig. 8 (*b*). When the current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to equal currents in the two windings neutralize each other. The ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. Evidently, an excess of current in one winding over that in the other will magnetize the relay. The Stearns differential relay, which is somewhat larger than the ordinary relay, has about 200 ohms in each winding.

BALANCING DIFFERENTIAL DUPLEX

23. Balancing a duplex or quadruplex system includes the adjustment of the various instruments and of the resistance and the capacity of the artificial line to equal exactly that of the main line, so that sending on the home key will not interfere in any way with the signals that are received at the home office from the distant office.

To balance the differential duplex, ask the distant office to open his key. If Philadelphia, Fig. 4, is the distant office, the line will then be grounded through the transmitter T_1 and the rheostat Y_1. Now, turn down the retractile spring of the home relay *R* and adjust the magnets, as would be done with an ordinary relay, for a weak current, in order to make the relay sensitive to the slightest inequality in the division of the current through its two coils. Make dots with the home key *K* and vary the resistance in the home rheostat *Rh* until the home relay no longer responds to the home signals. Then ask the distant office to make dots and readjust the home relay *R* to properly respond to the signals from the distant office as would be done with any ordinary relay. If a momentary kick follows each signal, it may be eliminated by varying the capacity of the condenser *C* and the resistance of the rheostat *Cr*.

To eliminate the kick at an office where the arrangement is like that shown at the Philadelphia end, the capacity of the condenser is adjusted and the position of the plug *n* varied until the kicks disappear. Leakage from the line wire to the ground is equivalent to a line wire of lower resistance, and when the leakage from the line increases, the resistance in the rheostat *Rh* will have to be diminished and the condenser may, also, need readjusting. If the signals from the distant office are stronger when the home key is open than when it is closed, there is not enough resistance in the home rheostat Y, and vice versa. The adjustment is not complete until the incoming signals are perfect with the home key held open or closed, or when writing with it.

POLAR DUPLEX SYSTEM

DISTINGUISHING FEATURES OF THE POLAR DUPLEX

24. A polar duplex telegraph system is one by means of which two messages may be sent simultaneously in opposite directions by controlling, at each end, the polarity of the potential connected toward the line. The essential devices in the polar-duplex set located at each end are a differentially wound polar relay, an artificial line, a potential reversing device called a *pole changer*, and a battery or dynamo, whose connections in the circuit are reversed by the pole changer.

25. Superiority of Polar Duplex.—In good weather, the differential, or single-current, duplex gives satisfaction, but its efficiency falls in proportion to the increase in the current that leaks from the line wire down every pole and support to the earth. If this leakage current would disappear when the distant key was open, all would be well; but it does not, and, consequently, the effective, or surplus, current in wet weather becomes too weak to overcome the already high tension of the retractile spring attached to the armature of the relay. The polar duplex overcomes this difficulty to a great extent, and will continue to work satisfactorily long after rain storms have rendered the single-current systems useless. On account of using currents flowing in opposite directions, the capacity of the line should give less trouble.

26. Differential Polarized Relay.—An essential feature of the polar duplex is the differentially wound polarized relay. Fig. 9 represents a polarized, or **polar**, relay, as it is also called, with the two coils connected in three different ways with the same battery. In (*x*) the current circulates only in the coil *c*. The direction of the current and the resultant direction of the lines of force and the polarity of the poles are as indicated. Although there is no current in the coil *d*, the lines of force created in the core by the current in the coil *c* will return to their original starting point through the path offering the least resistance to them, which is through the soft iron, as shown by the

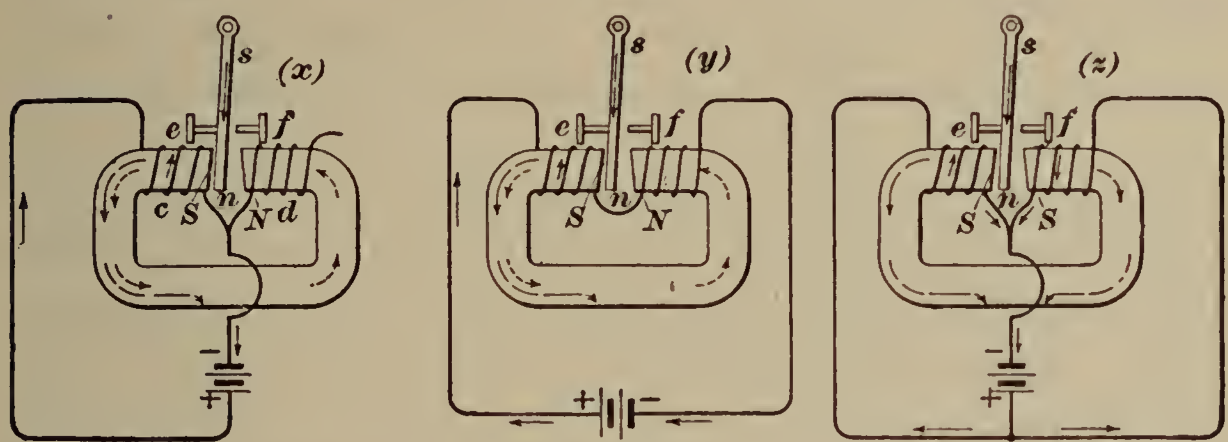


FIG. 9

dotted arrows, and not through the steel magnet, which has been omitted in this figure for the sake of simplicity. Thus the necessity of using the best quality of soft iron for this part of the relay is evident. On account of the lines of force produced by the permanent magnet, shown by arrows drawn with dashes, which make a north pole at *n* on the tongue, and those produced by the current in the coil *c*, shown by dotted arrows, there will be a strong south pole at *S*, and a weaker north pole at *N*. This will cause the armature to rest against the stop *e*. If the battery is reversed, the tongue will be drawn against the stop *f*.

27. In Fig. 9 (*y*), the same battery is connected so that the current flows through both coils, but the strength of the current will only be about one-half what it was in (*x*), because the two coils will have twice the resistance of one. The currents circulate through the two coils around the iron in the same direction, tending, therefore, to help and not to oppose each other in magnetizing the soft-iron core. Therefore, the intensity and direction of the magnetism produced in (*y*) will be the same as that in (*x*) and the armature will be held against the stop *e*.

28. In Fig. 9 (*z*), the two coils are connected differentially, so that the current from the battery divides into two equal portions, one portion flowing through each coil, but in opposite directions, around the iron. Consequently, the coils tend to magnetize the iron with equal forces in opposite directions, and they thus neutralize each other and produce no magnetism; but the permanent steel magnet polarizes the soft-iron parts the same as if there was no current in either coil. Hence, both cores equally attract the armature and it remains against whichever stop it happened to be previously. If the battery, in this case, is reversed, the two coils will still oppose and neutralize each other. Consequently, when connected as shown in view (*z*), the coils have no influence at all on the tongue, no matter what may be the strength or the direction of the current through the two coils.

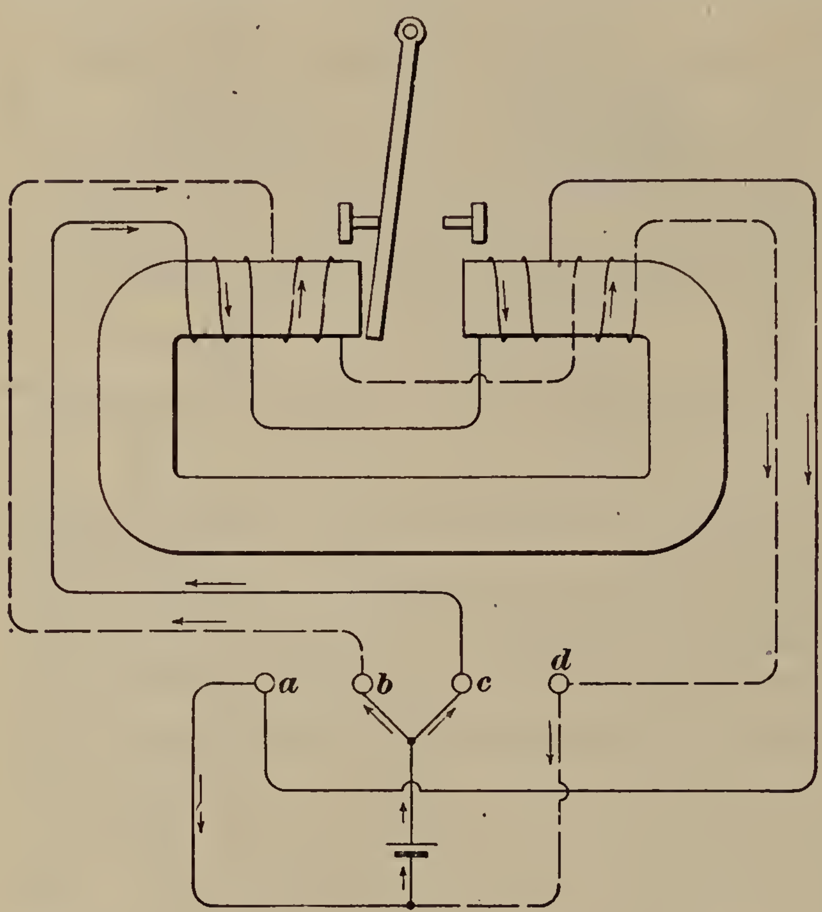


FIG. 10

29. Method of Winding a Differential Polar Relay. The differential polar relay is wound with two coils on each core in the same manner and for the same reasons as the differentially wound neutral relays. In the diagrammatic view of a differentially wound polar relay given in Fig. 10, the ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. When current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to the current in the two windings neutralize each other and an excess of current in one winding over that in the other will magnetize the relay.

Each of the four coils of a Western Union polar relay has about 2,780 turns of 36 B. & S. wire and a resistance of 200 ohms. Thus the line winding, or *line coil*, as it is called, although it consists of two coils, has a resistance of 400 ohms, and the artificial-line winding, which also consists of two coils, has, likewise, a resistance of 400 ohms. Polarized relays on duplex circuits require about 25 milliamperes, while on quadruplex circuits the minimum current required to work them varies from 15 to 18 milliamperes.

Some polar relays are wound with 300 ohms of enamel wire. Reversing a current of 3 milliamperes should properly work such a relay when the magnetic air gap, with the armature centered between cores, is from .035 to .04 inch on each side and the travel between contact points is .003 inch. The same conditions apply to the 400-ohm, silk-covered wire relay, as the latter possesses very few if any more turns. There is a flat multi-blade pocket-knife device, each blade differing in thickness and marked in thousandths of an inch, which is very useful in quadruplex departments for determining such distances.

30. Connections of Polar Duplex.—The connections of the polar duplex when dynamos are used to supply all current are shown in Fig. 11. *PR* and PR_1 are differentially wound polarized relays, the adjustable resistances *Rh* and *Cr* and the condenser *C* form the artificial line at the left-hand stations while Rh_1 and C_1 form the artificial line at the right-hand station. The artificial-line circuits are arranged in a slightly different manner at the two stations, in order to illustrate two methods used. The resistance *Cr*, called a *retarding coil* because it retards the discharge of the condenser, is placed in series with the condenser *C* and is adjusted until the artificial line charges and discharges neither slower nor faster than the line.

When a current is flowing through a wire, the difference of potential between two points near together is less than that between two points farther apart. As the charge that a condenser receives depends on the difference of potential at its terminals, the charge that the condenser C_1 receives may be regulated by connecting the upper terminal of the condenser to different coils of the rheostat Rh_1. The nearer this connection is made to the line, the greater will be the resistance and potential difference between the terminals of the condenser; and, hence, the greater will be the charge taken by the condenser. The portion of the rheostat Rh_1 between the condenser connection and the line acts also as a retarding coil. This is the later and better arrangement.

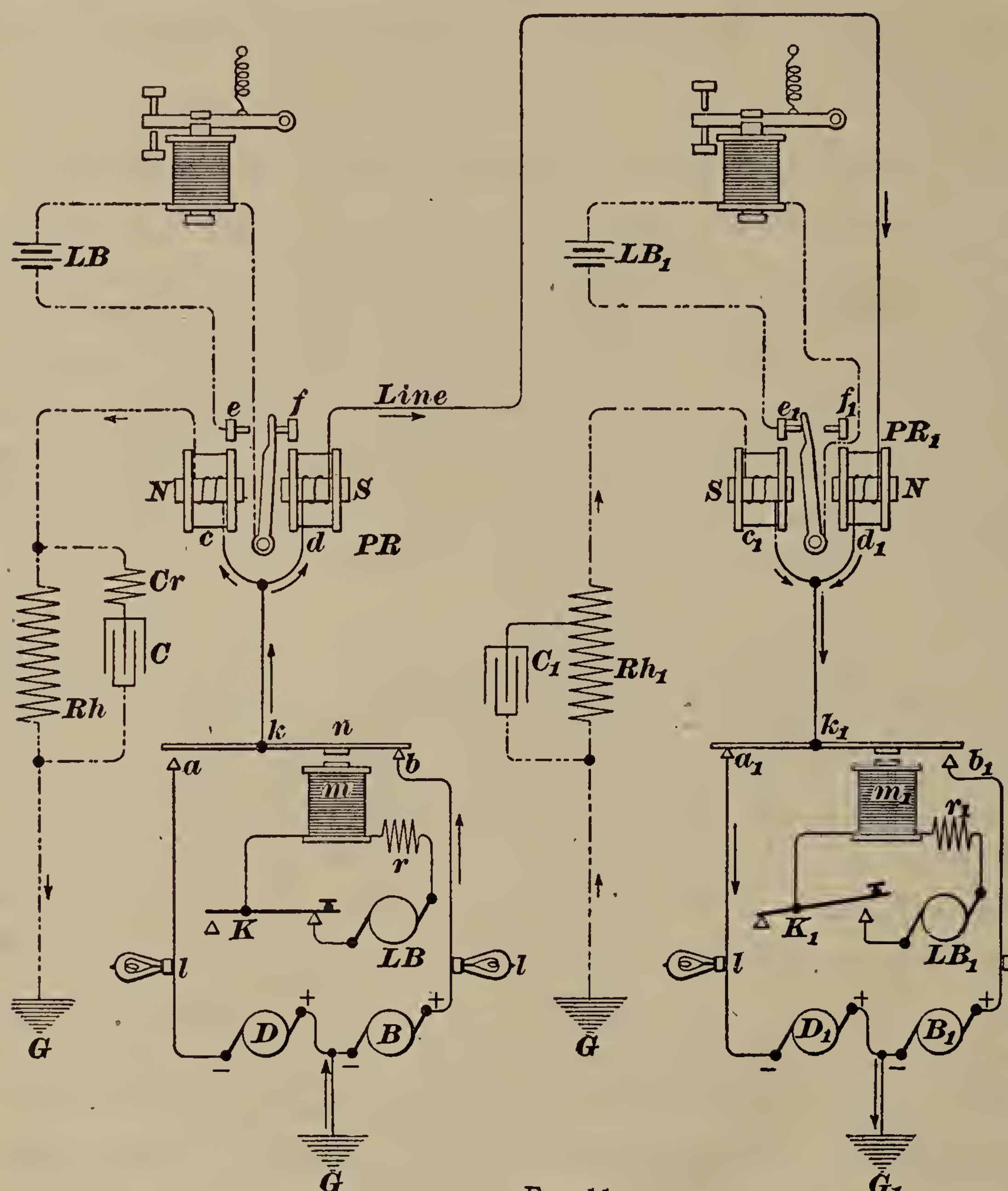


FIG. 11

31. The dynamo, or *walking-beam pole changer*, which is shown in Fig. 11, consists of a lever, or beam, k to which is fastened the iron armature n, two adjustable stops a and b, an electromagnet m, the current through which is controlled by the operator's key K, a 23- to 40-volt dynamo LB, and a resistance r that allows just sufficient current to flow to operate properly the pole changer. When the key K is closed, the positive pole of dynamo is connected through contact b to the beam k; when it is open the negative pole of dynamo D is connected through contact a to the beam k. The beam k, in moving from one position to the other, momentarily opens the circuit when in its intermediate position and the dynamos are never short-circuited.

In circuit with each machine is a non-inductive resistance l, which is either an incandescent lamp or a non-inductively wound coil of German-silver, or other high-resistance, wire. This resistance serves two purposes: It reduces sparking at the contact points, because it limits the strength of the extra current when the pole changer opens the circuit, and it prevents injury to the dynamo due to overheating in case there is a short circuit. For duplex and quadruplex circuits, this resistance varies from about 300 to 800 ohms. All four dynamos, D, B, D_1, and B_1, generate current at the same voltage. The connections at the two ends are identical, except for the slight difference in the artificial lines that has already been explained.

OPERATION OF POLAR DUPLEX SYSTEM

32. Both Keys Open.—When both keys K and K_1 are open, the beams k and k_1 of the pole changers rest on the rear contacts a and a_1, and, as the negative poles of two equal dynamos, one at each end, are, in this open position of the two keys, connected to the line, there will be no current flowing in the line coils d and d_1. However, there will be current in the two artificial-line coils c and c_1 and the direction in which the current flows around the soft-iron cores and the polarization of the armatures will be such as to hold the armatures of both polarized relays against their back stops f and f_1. The current in either artificial-line coil due to the home dynamo may be represented as having the strength of 1 unit.

33. Key *K* Closed.—If the western operator commences to send by pressing his key K, the positive pole of one dynamo B will be connected to the relay and line, in place of the negative pole of the other dynamo D. This will reverse the direction of the current through the artificial-line coil c, but its strength will remain the same, namely, 1 unit. The current in the line coils d and d_1 will now have a strength of 2 units, because the two dynamos B and D_1, which generate equal electromotive forces are now connected in series in the line circuit. Hence, a current of 1 unit flows through the artificial-line coil c and a current of 2 units through the line coil d, but the direction of the currents in the two coils, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing only through the line coil d in the direction shown by the arrow at that coil. This will produce a north pole at the left-hand end of the core on which the coil d is wound and a south pole at the right-hand end of the core on which c is wound and, consequently, the tongue, assuming it to have a south pole between the two cores, will remain against the back stop f. Thus, the closing of the home key K does not affect the home relay PR as long as K_1 the distant key remains on the rear contact a_1.

At the east end, the current in the artificial-line coil c_1 has not changed in strength or direction; it has a strength of 1 unit. In the line coil d_1, however, there is now a current of 2 units. The direction of the currents in the two relay coils d_1 and c_1, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit through the line coil d_1 in the direction shown by the arrow in that coil. This will produce a south pole at the left-hand end of the core on which the coil d_1 is wound and a north pole at the right-hand end of the core on which the coil c_1 is wound. Consequently, the tongue, assuming it to have, as before, a south pole between the two cores, will move against the front stop e_1 and close the local sounder circuit at the eastern office. Thus, the closing of the home key K, when the distant key K_1 is open, operates the polar relay PR_1 at the distant office, but does not affect the home polar relay PR.

34. Both Keys Closed.—If the key K_1 is now closed, the relay PR will be closed and the relay PR_1 will continue to remain closed until the key K is released. For when both keys are closed and the levers of the pole changers rest on their front contacts, the two dynamos B and B_1 are connected in opposition in the line circuit. Consequently, no current flows in either of the line coils d or d_1. The current in the artificial-line coil c_1 is reversed and will produce a north pole at the right-hand end of the core on which it is wound, and a south pole at the left-hand end of the core on which the coil d_1 is wound. But this polarity is the same as before and, therefore, the tongue of the polar relay PR_1 remains against the front stop e_1, being unaffected by the change in the currents caused by closing the home key K_1, although it has reversed the polarity applied to the circuit by the home dynamos.

At the western office the current in the artificial-line coil c has not changed in strength nor direction, but there is now no current in the line coil d. The direction of the current is such that it reverses the polarity of the cores, producing a north pole at the right-hand end of the core on which c is wound and a south pole at the left-hand end of the core on which d is wound. Consequently, the tongue of the home relay PR moves against the front stop e and closes the local sounder circuit. Thus, the closing of the distant key K_1 when the home key K is closed, closes the home relay PR, but does not affect the distant relay PR_1.

35. Key K_1 Closed.—If the western key K is now released, the distant K_1 remaining closed, the two dynamos D and B_1 will be in series in the line circuit, the current in the line coils of both relays will have a strength of 2 units, and the current through the artificial-line coil c will be reversed in direction, but will have the same strength as before, namely, 1 unit. The direction of the currents in the coils c and d is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing from the line through coil d. This produces a south pole at the left-hand end of the core on which the coil d is wound and a north pole at the right-hand end of the core on which c is wound. Consequently, the polarity is such that the tongue of the home relay PR remains against the front stop e when the home key K at the western office is released.

Thus, the opening of the home key K does not change the polarity of the home relay PR. At the eastern station the effect of a current of 2 units flowing from the dynamo B_1 through the coil d_1 to the line, and a current of 1 unit from the same dynamo flowing through the coil c_1 to the artificial line, is equivalent to a current of 1 unit flowing from the same dynamo B_1 through only the line coil d_1. This produces a north pole at the left-hand end of the core on which d_1 is wound and a south pole at the right-hand end of the core on which c_1 is wound, thus causing the tongue of the relay to move from the front stop e_1 to the rear stop f_1. Thus, the opening of the home key K, while the distant key K_1 is closed, produces no effect on the home relay PR, but does open the distant relay PR_1.

It has, therefore, been shown that no matter what may be the position of the distant key, the operation of the home key does not affect the home relay, but that it does properly operate the distant relay.

36. Keys in Intermediate Positions.—It may be well to consider what happens to the relay during the short interval between the opening of the circuit at one contact of the pole changer and the closing of the circuit again at the other contact of the same pole changer. Suppose that the lever of the distant pole changer k_1 rests on the rear stop a_1, and that the lever of the home pole changer k, in moving from the rear to the front contact, remains in an intermediate position, touching neither a nor b. In this position only the dynamo D_1 is in the circuit. It supplies a current of 1 unit to the coil c_1. The artificial line Rh at the western office, the coils c and d, the line and the coil d_1 are in series with the dynamo D_1. The resistance of this circuit is double that of the line and the two line coils d and d_1, and, consequently, the current in this circuit will have a strength of $\frac{1}{2}$ unit. The current of a strength of $\frac{1}{2}$ unit in coil d_1 will oppose the current of 1 unit in c_1, but the magnetism due to a resultant current of $\frac{1}{2}$ unit flowing from the artificial line through coil c_1, produces a south pole at the right-hand end of c_1 and, therefore, tends to hold the tongue of the distant relay PR_1 against the back stop f_1, where it is already. Thus, the distant relay PR_1 will not be affected until the lever *k* of the pole changer touches the front stop *b*. A current of ½ unit flows in the same direction through both coils *c* and *d*, so that their magnetizing forces help each other and produce a resultant magnetism of the same polarity and strength as when the lever *k* of the pole changer rested on the rear stop *a*. Consequently, the home relay *R* is not affected, and the tongue remains stationary against the rear stop *f*.

Suppose that the levers of both pole changers are in an intermediate position at the same instant. Evidently all four dynamos are cut off and there is no current in any part of the system.

TABLE II

COMBINATIONS OF KEY-AND-RELAY POSITIONS

West Key *K*	East Key K_1	Western Office				Eastern Office			
		Current in		Difference	West Relay *PR*	Current in		Difference	East Relay PR_1
		Coil *d*	Coil *c*			Coil d_1	Coil c_1		
Open	Open	0	−1	+1	Open	0	−1	+1	Open
Closed	Open	+2	+1	+1	Open	−2	−1	−1	Closed
Open	Closed	−2	−1	−1	Closed	+2	+1	+1	Open
Closed	Closed	0	+1	−1	Closed	0	+1	−1	Closed

But, now, the magnetism produced in the soft iron by the permanent steel magnet will hold the tongues on whichever side they happen to be, thus preventing any false signals.

37. Key-and-Relay Positions.—Let the current flowing from the home pole-changer lever through either coil on the home relay toward the line or artificial line be called a *positive current;* and the current flowing from the line or artificial line toward the home pole-changer lever be called a *negative current.* Furthermore, let the current that flows through one artificial-line circuit due to one dynamo be considered as having a strength of 1 unit; and let the end of the tongue between the cores of the polar relay be assumed to be a south pole. Then the four possible combinations of key-and-relay positions and the currents in each coil may be summarized as shown in Table II.

The quantities in the difference column are obtained by subtracting the quantities in the c or c_1 column from the quantities in the d or d_1 column, respectively. It will be noticed that whenever the current in the line coil minus the current in the artificial-line coil of the same relay is $+1$, the relay is open; and that whenever it is -1, the relay is closed. Furthermore, it will be noticed that the eastern relay is open or closed according to whether the western key is open or closed.

POLE CHANGERS

38. A very essential instrument in the polar duplex and quadruplex systems is the **pole changer.** This is a device for reversing the battery and, consequently, for reversing the direction of the current in the circuit. It shifts the line from one pole of a battery to the opposite pole, and, simultaneously, does the same with the wire connected to the ground. Where dynamos are used, it shifts the line from one pole of one dynamo to a pole of opposite polarity on another dynamo. Poles of opposite polarity of the two dynamos are permanently grounded. Thus the operation of a pole changer changes the direction of the current in some part, at least, of the circuit.

A device that will reverse the direction of the current in the circuit without opening the circuit is called a **continuity-preserving,** or **circuit-preserving, pole changer.** Such a pole changer is preferable to one that opens the circuit when shifting the line from one pole of the battery to the opposite pole. While continuity-preserving pole changers are generally used where gravity cells are employed for main-line batteries, they are not practicable, and are not used where dynamos have replaced gravity batteries.

39. Continuity-Preserving Pole Changer.—The principle of continuity-preserving pole changer is shown in Fig. 12. The battery B is connected to two movable spring contact strips a and d. The line wire is connected to the lever of the key K, and the fixed piece *b* is connected to the ground. In the normal, or open, position of the key, as shown in (*x*), the positive pole of the battery is connected through the strip *a* and contact *c* to the key lever and to the line; the negative pole of the battery is connected through the strip *d* and the fixed contact piece *b* to the ground *g*. In this position of the key, the direction of the current through the circuit is as shown by the arrows. If the key is depressed, or closed, as shown in (*y*), the direction of the

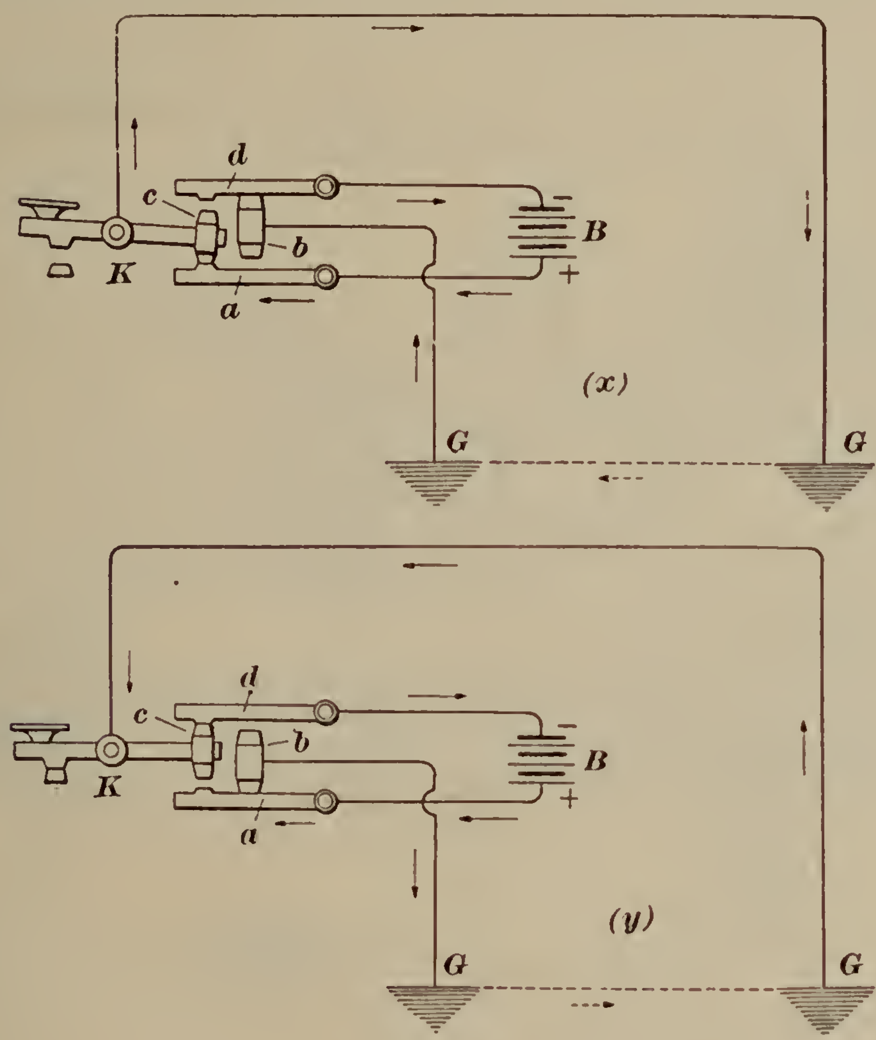


FIG. 12

current in the line and in the ground circuit, as shown by the arrows, is the reverse of that shown in (*x*).

In passing from one extreme position to the other, the key momentarily short-circuits the battery. For the spring strips *d* and *a* may be made flexible enough and so adjusted that as the key in (*x*) is pressed down and the contact *c* moves up, the moving contact *c* first touches the spring strip *d*. Then the spring strip *a* touches the fixed contact *b*, next the moving contact *c* parts from the spring strip *a* and finally pushes the spring strip d away from the fixed contact b, giving the position of the contacts shown in (y). The reverse happens when the key moves in the opposite direction. Thus, the contact c momentarily short-circuits the battery and preserves an uninterrupted path from the line to the ground. This short-circuiting does not injure a gravity battery, on account of its rather high internal resistance. It may be a little hard on the contacts,

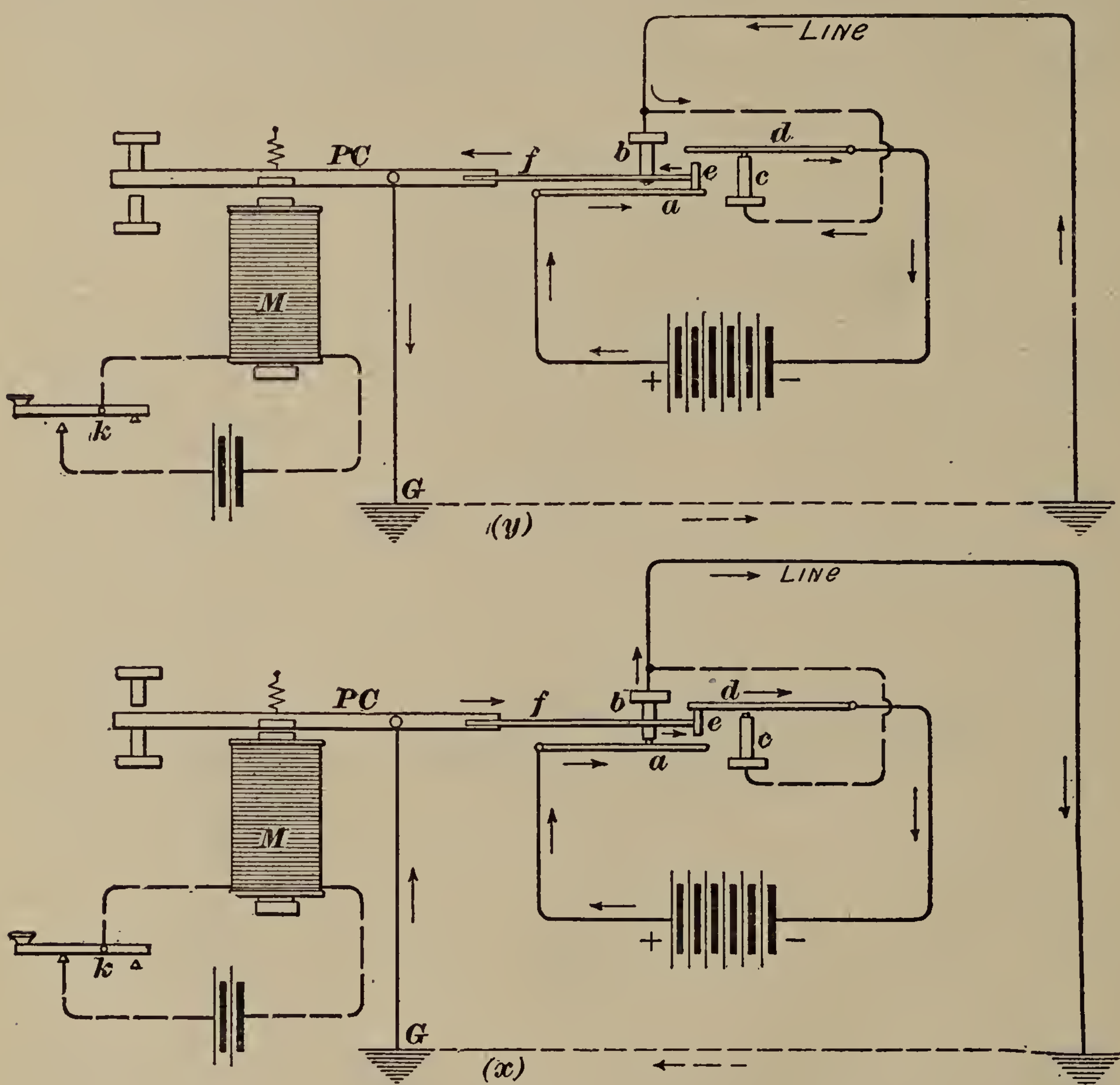


FIG. 13

due to the arc that is formed when the short circuit is opened, but it is not so serious as to render the method impracticable. The desirable feature of this pole changer lies in the fact that the battery is reversed with the least possible interference with the line current. In practice, the lever of the key is never manipulated directly by hand, but by means of an electromagnet.

40. B. & O. Pole Changer.—In Fig. 13 are shown the two positions of a pole changer known as the **B. & O.** (Baltimore and Ohio Railroad) **pole changer.** The contact screw *b* is placed behind the lever *f* and never touches it. When the key *k* is open, the position of the contacts and the direction of the current is as shown in (*y*). When the key *k* is closed, the magnet *M* draws down the forward end of the lever *PC* of the pole changer, causing the moving contact *e* to push the spring strip *d* away from the contact screw *c*, and allowing the other spring strip *a* to rest against the contact screw *b*, thus giving the position of the contacts shown in (*x*). The springs *d* and *a*

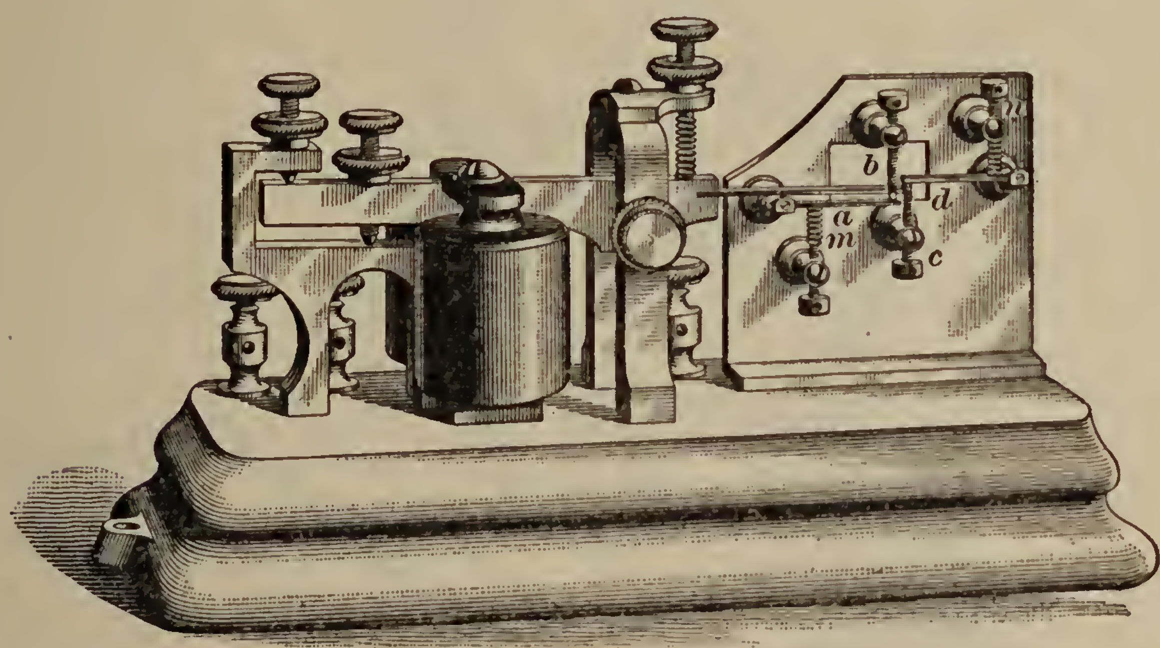


FIG. 14

may be made long and flexible enough and so arranged that, as the lever *f* moves up, the spring *a* first touches the screw *b*, then the moving contact *e* touches the other spring *d*, next the moving contact *e* parts from spring *a*, and, finally, the contact *e* pushes the spring *d* away from the contact screw *c*. The arrows show the direction of the current. This is a so-called continuity-preserving pole changer. It momentarily short-circuits the battery because *e* touches *d* before it leaves *a*.

This pole changer, as made by Bunnell & Co., is shown in Fig. 14. The contact springs *a* and *d* have bearing upon them adjustable springs *m* and *n*. The stop-screws *b* and *c* are also adjustable. These screws and contacts are not enclosed and are easy of access for the purpose of adjusting and cleaning. The rest of the instrument resembles an ordinary sounder.

41. Western Union Gravity-Battery Pole Changer. The so-called clock-face pole changer used by the Western Union Telegraph Company, where gravity main-line batteries are employed, is shown in Fig. 15. The contacts are enclosed in a case having a glass front, so that as much dirt and dust may be kept from them as is possible. The glass front enables one to observe the operation and condition of the contact points.

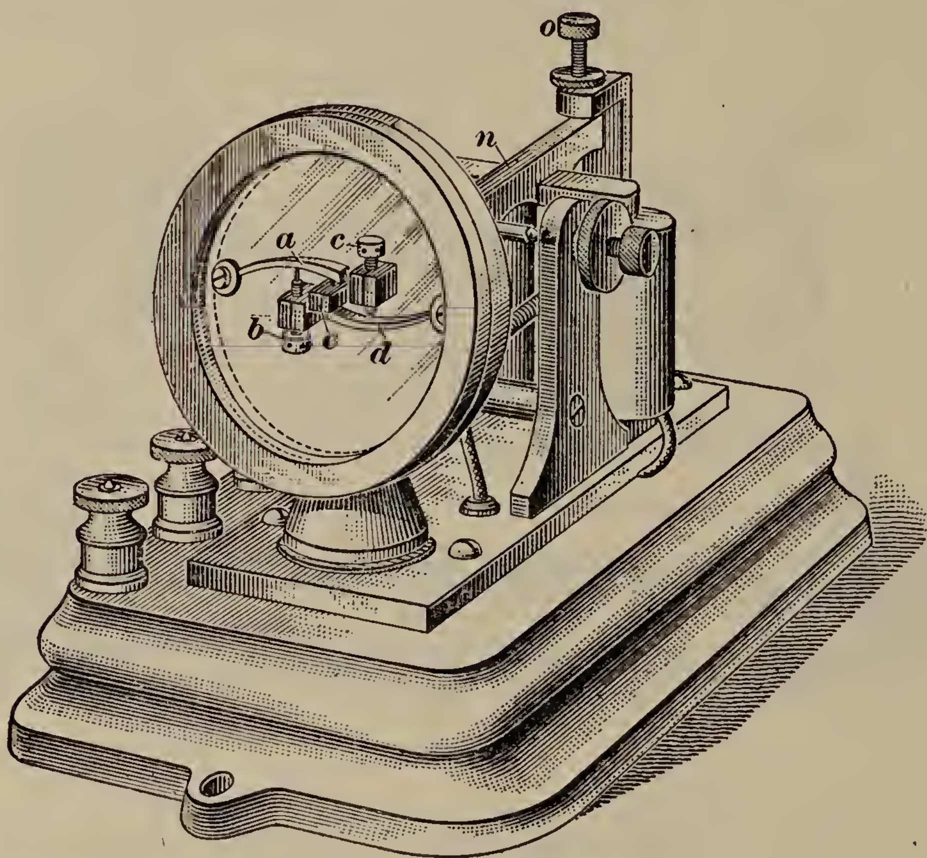


FIG. 15

The principle of this pole changer may be understood by referring to Fig. 16. The centerpiece *e* is fastened to the end of an armature lever and moves up and down. When down, as shown in (x), the positive pole of the battery B is connected through the strip *a* and the stop *b* to the line; the negative pole of the battery is connected through the strip *d* and the movable contact *e* to the ground G. The arrows show the direction of the current flowing in the various parts of the circuit. The reverse position is shown in (y).

This is a continuity-preserving pole changer. It momentarily short-circuits the battery in the intermediate position and preserves a closed circuit at all times between the line and the ground *G*. As contact *e* moves upwards, the spring *d* touches the stop *c*; then the contact *e* touches the spring *a* and pushes it away from the stop *b*; finally, the contact *e* parts from the spring *d*. However, the movable piece *e* is in contact with both springs *a* and *d* only momentarily; in fact, all these changes

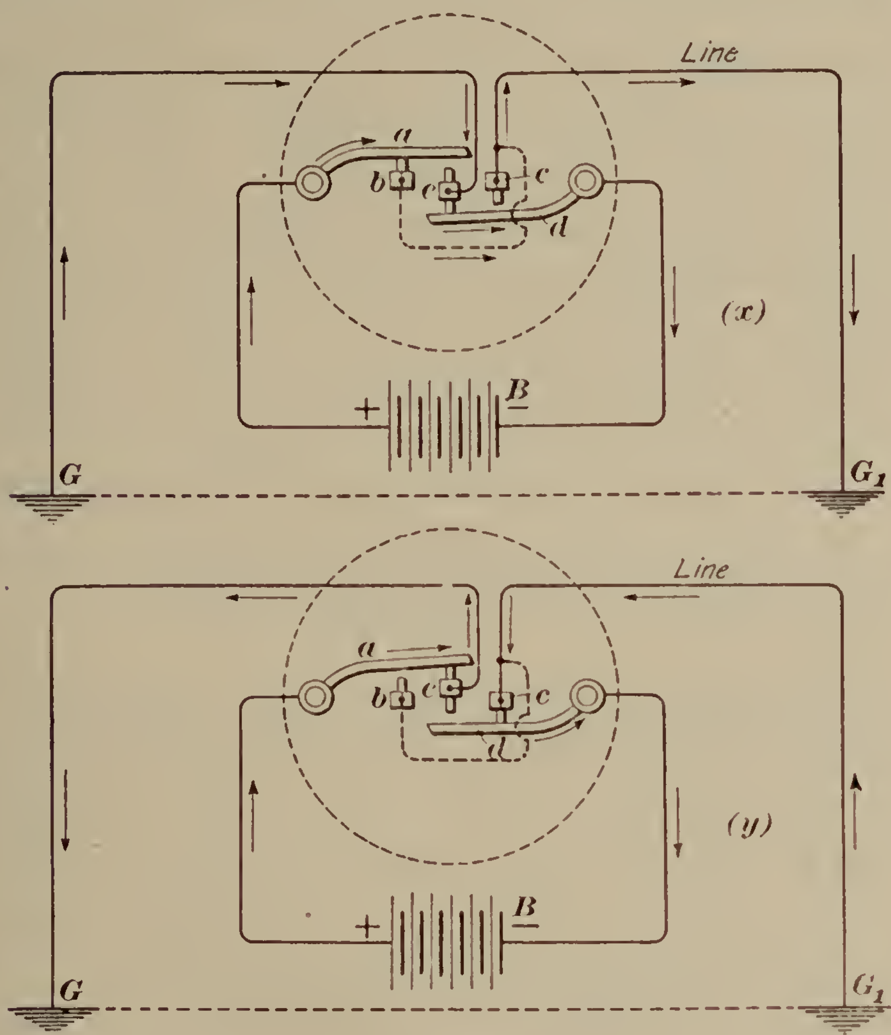


Fig. 16

follow one another very rapidly and the battery is short-circuited for only an instant. When the contact *e* moves downwards, the contacts are made and broken in a similar manner. The parts shown in both Figs. 15 and 16 are similarly lettered. In Fig. 15, *n* is the armature lever, on the front end of which is fixed the movable contact *e*. The stops *b* and *c* are in contact with the case and are connected to one binding post on the base. The springs *a*, *d* and the *e* end of the lever *n* are all insulated and connected to separate binding posts.

42. Dynamo Pole Changers.—Theoretically, there should be no difference in the efficiency of a duplex or quadruplex circuit whether it is supplied with current by a dynamo or by gravity cells in first-class condition. But in practice, the dynamo has been found to be the more economical and reliable source of energy. The use of gravity batteries, however, permits the employment of the continuity-preserving pole changer, for as each line has its own battery the direction of the current in any line can be reversed without interfering with the working of any other line. Besides, the continuity-preserving transmitter is less liable to interfere with the signals on the neutral relay in the quadruplex system than the walking-beam pole changer. But continuity-preserving pole changers cannot be used with dynamos because one dynamo furnishes the current to all lines requiring the same polarity and voltage; therefore, it is not practical to reverse the connections of the dynamo in one circuit without reversing it in all the others. A separate dynamo is therefore required for each polarity at each end, but not for each multiplex set at each end, and one pole of each machine is permanently grounded.

43. With dynamos it has been found advisable to use a pole changer that does not short-circuit the machines, but which opens the circuit connected to one pole of one dynamo slightly before it connects the circuit with the opposite pole of the other dynamo. If a continuity-preserving pole changer were used, it would at every reversal, where 350-volt machines are employed, short-circuit 700 volts and cause the formation of bad arcs at the contact points. This would soon put the contact points in very bad condition, and perhaps damage the dynamo on account of the heat produced.

To avoid these difficulties, the so-called **walking-beam pole changer**, shown in Fig. 17, is used. The line is connected to the beam *a b*; the positive pole of one dynamo *C* is connected to the contact stop *e* under one end *a* of the beam, and the negative pole of the second dynamo *D* is connected to the contact stop *f* under the other end *b* of the beam. The positive pole of one dynamo *D* and the negative pole of the other *C* are permanently grounded at *G*. Thus, when the key *K* is closed, the positive pole of dynamo *C* is connected to the line through the beam *a b*, and when the key is open, the negative pole of *D* is connected to the line. The beam *a b* in moving from one position to the other, momentarily opens the line circuit when in its inter-

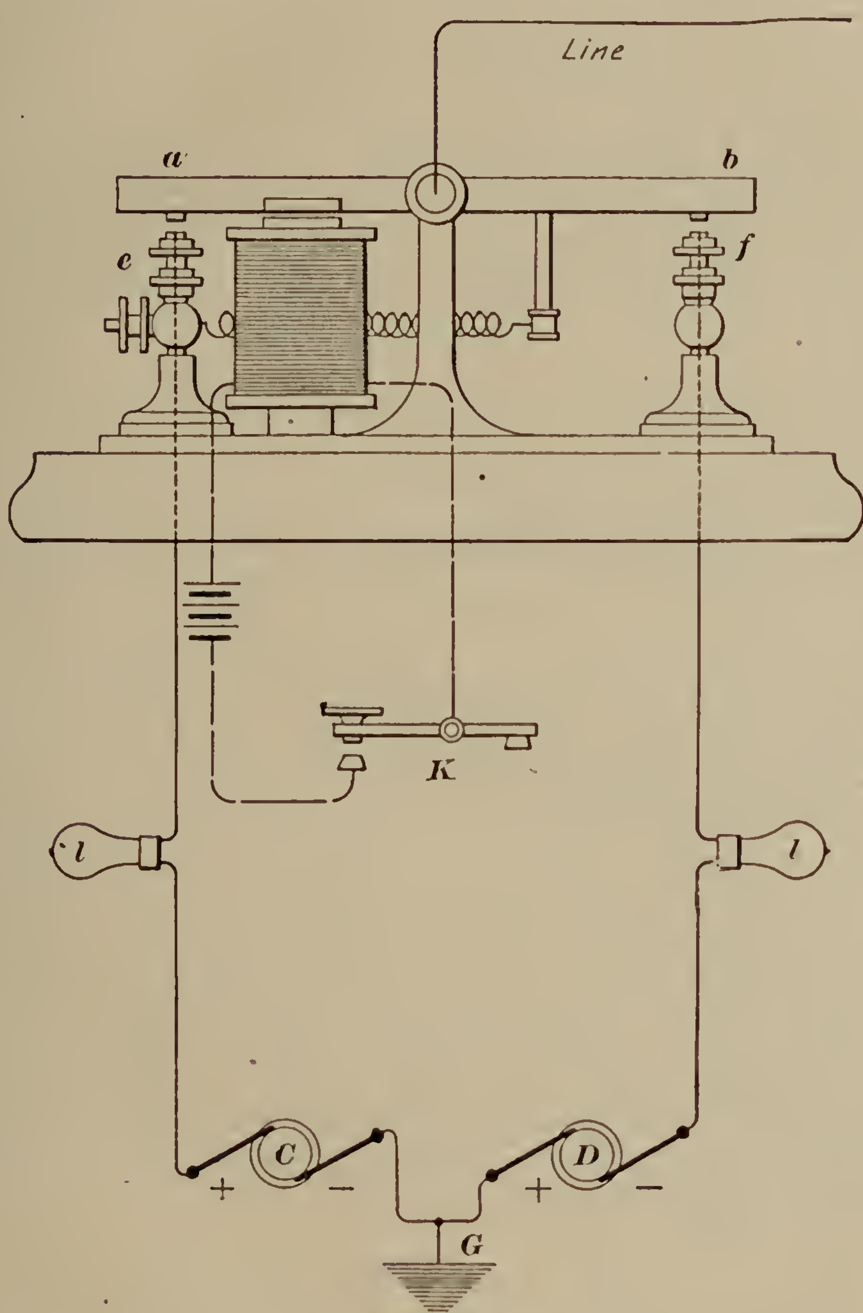


FIG. 17

mediate position, as is shown in this figure, but the dynamos are never short-circuited.

In circuit with each machine is a non-inductive resistance *l*, either an incandescent lamp or a non-inductively wound coil of German-silver, or other high-resistance, wire. This resistance serves two purposes: it reduces sparking at the contact points, because it limits the strength of the extra current when the pole changer opens the circuit, and it prevents injury to the dynamo due to overheating in case there is a short circuit. For quadruplex circuits, this resistance varies from 300 to 800 ohms.

TABLE SWITCH

44. A form of switch that is extensively used on the tables, or desks, in connection with duplex and quadruplex systems is shown in Fig. 18. Along the top is a row of seven screws, or binding posts, to which all wires running to the switch are fastened. Along the bottom is a row of six contact buttons. The buttons *1*, *3*, *4*, and *5* are connected under the switch to the binding posts, as shown by the dotted lines. The buttons *2* and *6* are idle buttons; that is, they have no wires connected to them. The switch arm *A* may rest on button *1* or button *2*, *B* on *3* or *4*, and *C* on *5* or *6*. This makes a very convenient switch; its use will be apparent when diagrams for the dynamo duplex and quadruplex systems are given. A similar switch, that is extensively used, has only two arms, which are mechanically joined together by a cross-bar having on it a handle by means of which both arms are simultaneously moved to the right or left.

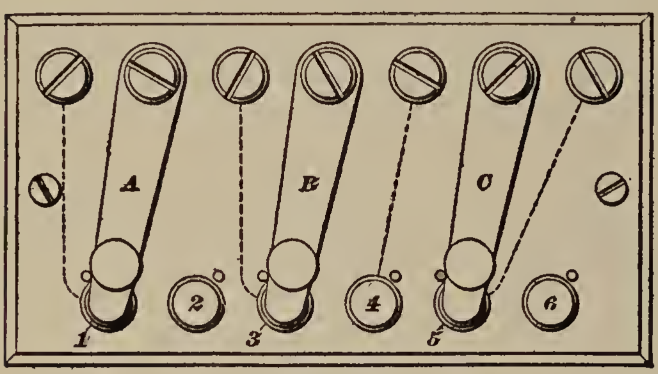


Fig. 18

POLAR DUPLEX OPERATED BY GRAVITY BATTERY

45. The practical arrangement of a polar duplex set at an office where gravity cells are used is shown in Fig. 19. All the apparatus and connections have already been explained except the use of the switch *H* and the resistance *Gc*, called the *ground coil*. This resistance need not necessarily be adjustable; it may be simply a coil having a fixed resistance. The resistance from *r* through the ground coil *Gc* to G_2 should be equal to that of the circuit from *p* through the pole-changer contacts and main battery *B* to the ground *G*. When the duplex set is in operation, the switch *H* rests on *p*; but in order to balance the set, it is desirable to cut off the pole changer and the battery *B*, but to keep the resistance of the circuit the same. This is accomplished by turning the switch *H* to *r*. The resistance of *Gc* should be equal to the internal resistance of the main battery *B*. Here *PC* represents a continuity-preserving pole changer suitable for use with gravity cells, such as has been shown in Figs. 14 and 15; *K* is the sending key and *S* is the receiving sounder.

POLAR DUPLEX OPERATED BY DYNAMOS

46. In Fig. 20 is shown the arrangement of the polar duplex when dynamos are used to operate the system. The walking-beam type of pole changer and the switch *M* replace the continuity-preserving pole changer and the simple switch *H* shown in Fig. 20 in which gravity main-line batteries were used. In order to avoid confusion, the local receiving and sending circuits are shown separately in Fig. 21. The contact buttons *u* and *z* on the switch *M*, Fig. 20, are idle, or insulated, and are used merely to rest the arms *o* and *q* upon when it is desirable to entirely cut off the main-line dynamos *D* and *F*. When the system is in operation, the switch arms *o*, *p*, and *q* rest upon the buttons *t*, *v*, and *r*, respectively. When the arm *p* rests upon the button *w*, the main circuit is connected through the ground coil *Gc* to the ground at G_2 instead of through the pole changer and dynamo *F* or *D* to the ground *G*. Thus, the polar relay is entirely disconnected from the home dynamos. This is the position of the switch arm *p* for balancing the system. The resistance of the circuit from the button *w* through the ground coil *Gc* to the ground G_2 is made equal to that of the circuit from the button *v* through the pole-changer contacts, one lamp *l* and one dynamo to the ground *G*. The switch *Gc* is practically equal in resistance to that of one of the lamps *l*. At *N* is shown the form of switch used where a dynamo is employed to operate the local sending and receiving circuits.

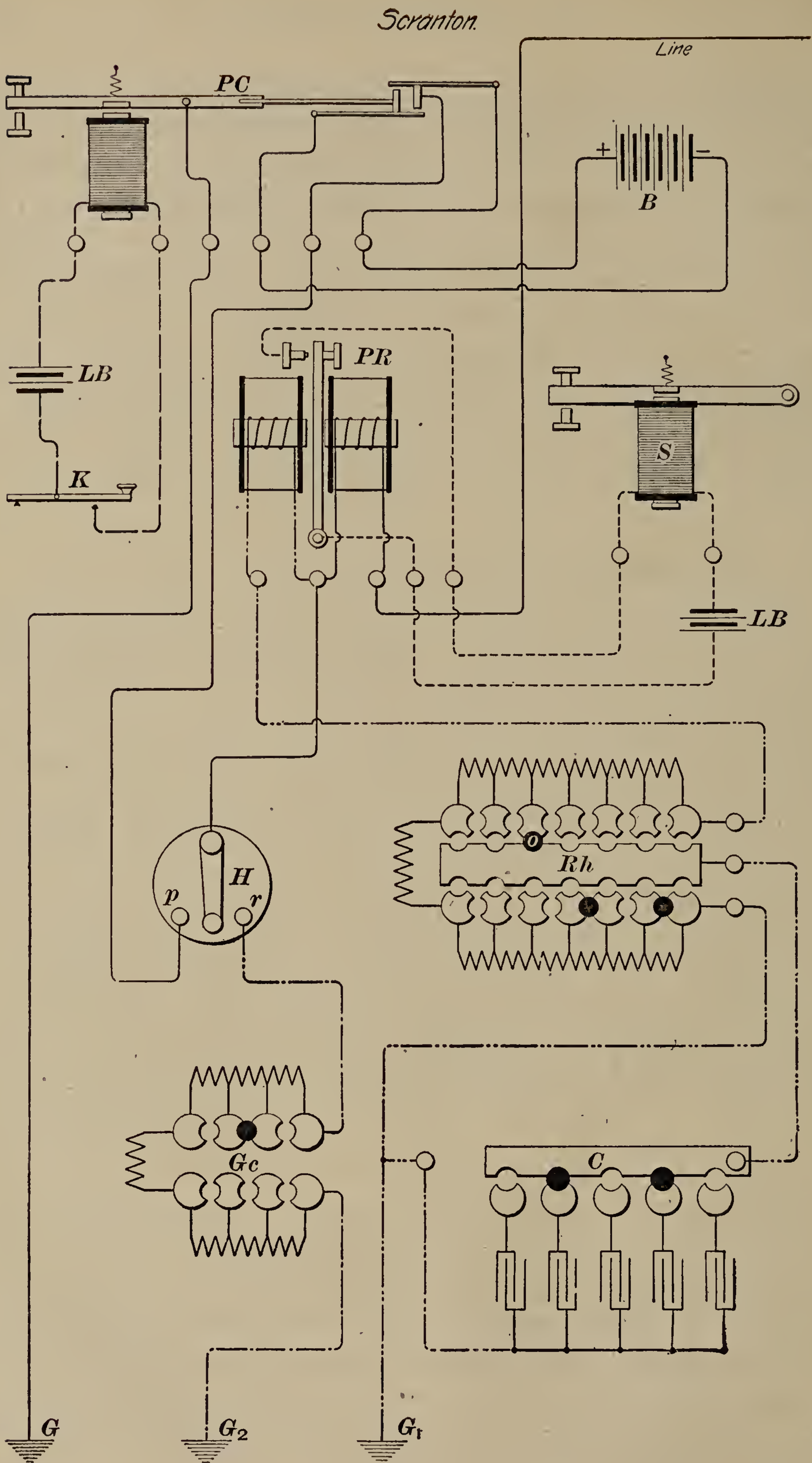


FIG. 19

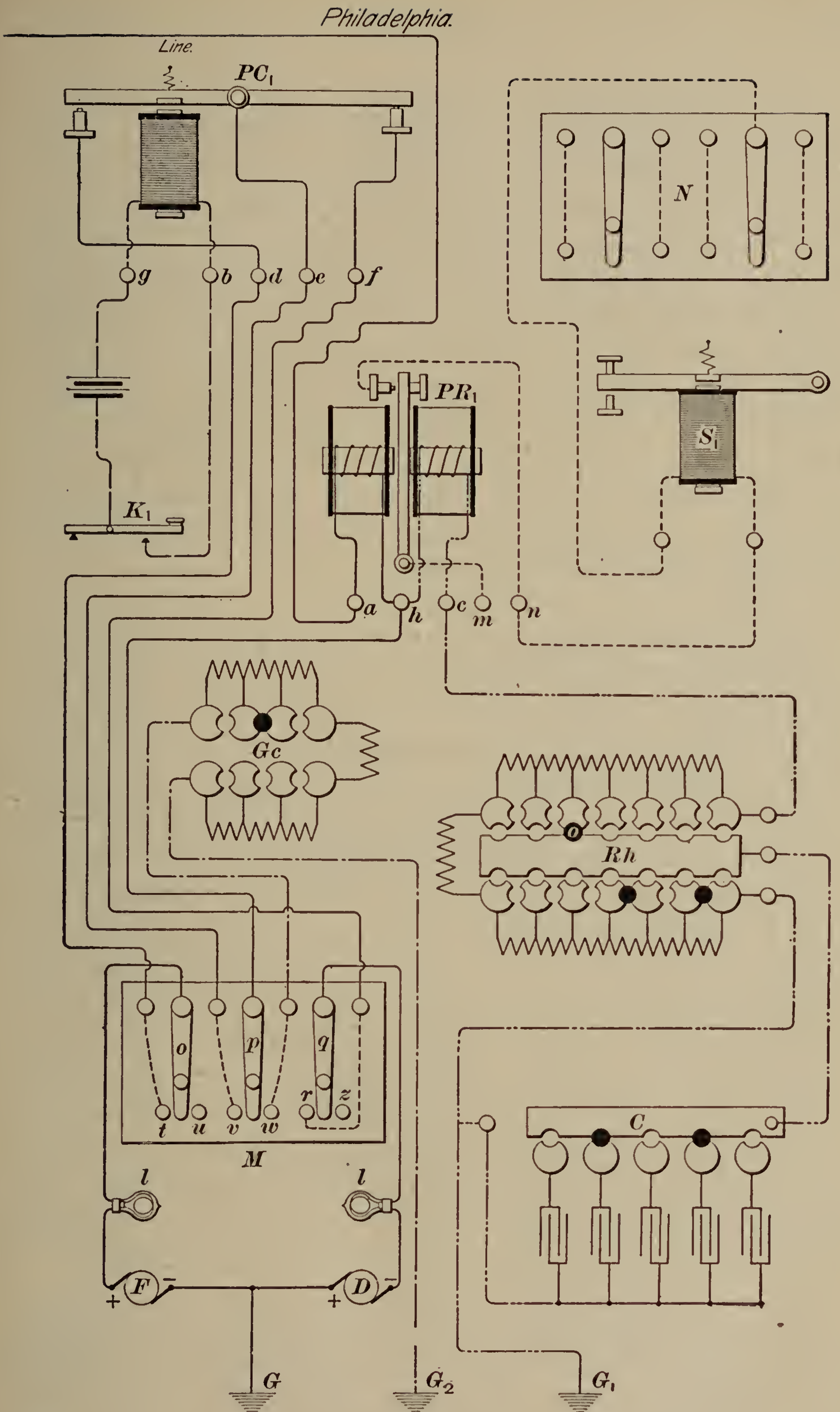

Philadelphia.
Line.
PC_1
g
b
d
e
f
N
PR_1
S_1
K_1
a
h
c
m
n
Gc
Rh
o
p
q
t
u
v
w
r
z
M
C
l
l
F
D
G
G_2
G_1

Fig. 20

47. Local Circuits Supplied From One Dynamo. In Fig. 21 is shown the connections for the sending and receiving circuits in Western Union offices where a 23-volt dynamo *LB* is used to supply current for the pole changer and sounders in both the sending and receiving sides of the circuit. All sounders in the receiving side are controlled by the polar relay *PR*, and the pole changers and sounders in the sending side are controlled either by the key *K* or K_1 at the main office, or by the key K_2 at the branch office. By means of the switch *W*, the 23-volt dynamo *LB* may be cut off and the circuit connected to the ground G_1 through the lamp l_1. This is convenient when there is a battery or dynamo in the circuit at the loop switch or elsewhere, or when another duplex set connected to this same dynamo is repeating into this set.

48. Sounders are included in the sending circuit at the branch office to enable the branch-office sending operator to hear his own writing and, also, to enable the main-office and branch-office operators to communicate with each other over the sending side. Sometimes a sounder is placed in the sending circuit at the main office, especially when the pole changer is adjusted so close that it is difficult for the main-office operator to read from the sounds made by it. The receiving side cannot well be used for communication between the main and branch offices, and, consequently, no keys are included in that side. For the convenience of the operator on the receiving side at the main office, the sending side is often extended over to the receiving table, where an extra key K_1 is inserted in the sending circuit. This enables the receiving operator to communicate, without leaving his desk, with the distant main office. Of course, he cannot do this if the sending side is in use at that time. The pole-changer and sounder coils have the same resistance, usually 4 ohms, in each instrument.

The branch-office loop, containing on the receiving side, or *receiving leg*, as it is called, the sounder S_1, and on the sending leg the sounder S_2 and the key K_2, is connected through a wedge and spring jack *LS* at the loop switchboard in the main office with the table switch *N*. When the switch arms *o* and *q* rest

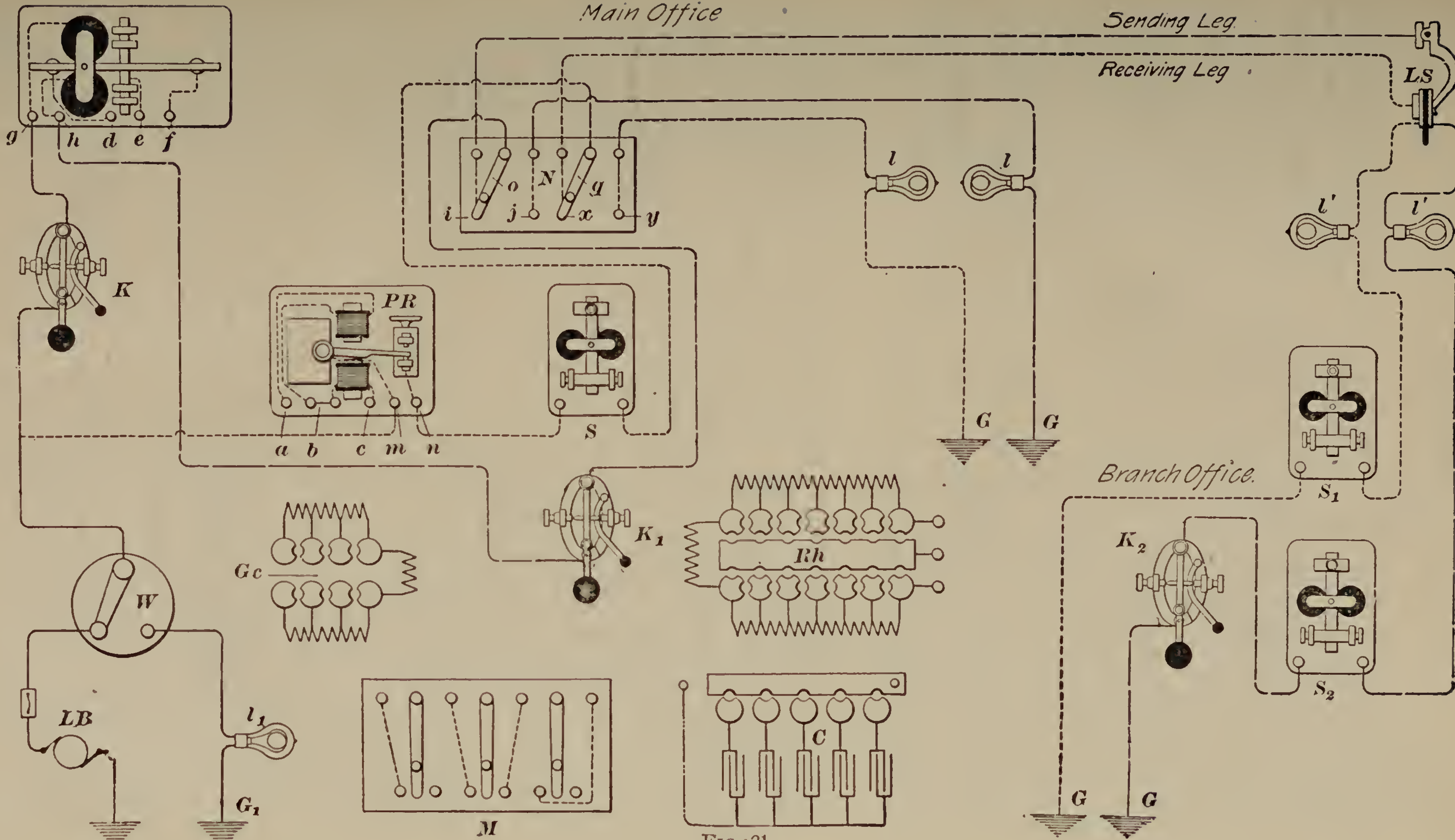
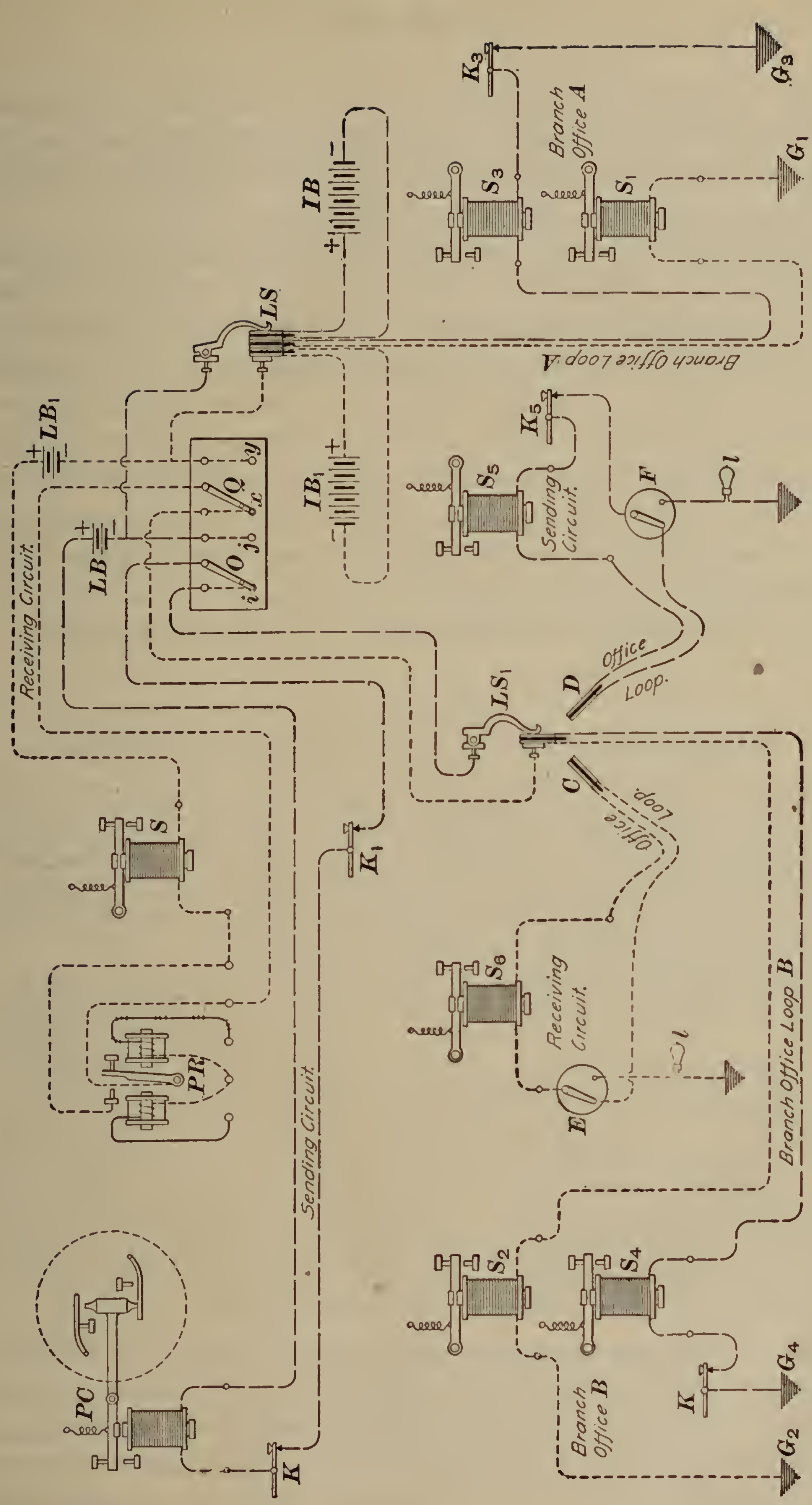

Main Office
Sending Leg
Receiving Leg
LS
l'
l'
l
l
G
G
Branch Office.
S
S1
S2
K
K1
K2
PR
a b c m n
g h d e f
i j o N g x y
Rh
Gc
W
LB
l1
G1
M
C
G
G

FIG. 21

on the buttons *i* and *x*, respectively, the main-office sending and receiving circuits are in series with the branch-office sending and receiving circuits respectively. By means of various resistance lamps *l′*, all loop circuits are made to have about the same resistance, so that any branch office may be connected through the loop switch to the duplex set, and the 23-volt dynamo will still furnish the proper amount of current. The branch-office loop may be readily cut off by moving the switch arm *o* to contact *j* and arm *q* to contact *y*. This substitutes two locally grounded circuits, each containing a lamp *l*, for the branch-office sending and receiving legs. These lamps *l* have the proper resistance, so that shifting the switch arm *o* from contact *i* to contact *j* and the switch arm *q* from contact *x* to contact *y* does not change the strength of the current.

49. Several Loops in One Circuit.—It is practicable to connect several offices in one local circuit on either or both the sending or receiving legs of a duplex or quadruplex circuit. In Fig. 22 the regular office set, operated by local gravity batteries *LB*, and LB_1, is shown connected with the two branch offices *A* and *B* through the loop switches *LS* and LS_1. Intermediate gravity batteries *IB* and IB_1 are connected in the sending and receiving sides of the circuit, respectively. These batteries must have their poles so connected at the switch *LS*, that battery *IB* will be in series with *LB*, and IB_1 in series with LB_1, otherwise they will be opposing instead of assisting one another. In offices where only dynamos are used, there would be no gravity batteries at *LB*, LB_1, *IB*, and IB_1. The resistance of the loop circuits would then be so adjusted that the local-circuit dynamo, such as *LB* in Fig. 21, would furnish the desired amount of current. Or, two small dynamos of proper voltage used as intermediate batteries, one in place of *IB* and the other in place of IB_1, could be employed; in this case there would be no batteries at *LB* and LB_1.

With the switch arm *O* resting upon the contact button *i*, the sending leg may be traced from the ground G_3 through $K_3-S_3-IB-LS-LB-$magnet of the pole changer $PC-K-K_1-$switch arm $O-i-LS_1-S_4-K-G_4$ and back through



Receiving Circuit.
LB₁
LB
Q
O
i
j
x
y
IB₁
IB
LS
LS₁
Branch Office Loop A.
Branch Office A
K₃
G₃
S₃
S₁
G₁
S₅
K₅
Sending Circuit.
F
l
Office Loop.
D
C
Office Loop.
S
PR
K₁
Sending Circuit.
S₆
Receiving Circuit.
E
l
Branch Office Loop B
S₂
S₄
K
G₄
G₂
Branch Office B
PC
K

FIG. 22

the ground to G_3. With the switch arm Q resting on contact x, the receiving leg may be traced from the ground $G_1-S_1-IB_1-LS-LB_1-S$ – contact points of the polar relay PR – switch arm $Q-x-LS_1-S_2-G_2$ – ground back to G_1.

Extra main-office sending and receiving circuits may be easily included by inserting the wedge C in the spring jack LS_1 on the receiving side, and the wedge D on the sending side of the wedge already in the jack; in which case the switches E and F must be turned to the left. By turning either or both of these switches to the right, either or both of the receiving and sending legs extending to the branch office B may be cut off. By turning the switch arm O to contact j and the switch arm Q to contact y, all the loop circuits are cut off, leaving only the sounder S and battery LB_1 in the receiving side and the key K, the magnet of the pole changer PC, and a battery LB in the sending side.

BALANCING THE POLAR DUPLEX SYSTEM

50. In order to explain the method of balancing a polar duplex system, it will be supposed that a line between Scranton and Philadelphia is to be worked on this system, that Scranton, Fig. 19, is the home office and Philadelphia, Fig. 20, is the distant office, and that the home set is to be balanced.

The insulation of a line will vary with the weather, and the lower the insulation, the lower will be the apparent resistance and capacity of the line. Hence, a change in the weather that is sufficient to alter the insulation of the line may require a readjustment, to a greater or less extent, of both the rheostat and the condenser. This is the case even more with a quadruplex than with a duplex circuit, and should not be forgotten when one is at work on such systems. Polar relays on duplex circuits require 25 milliamperes to properly work them.

51. Centering Armature of Polar Relay.—To center the armature of the polar relay Scranton will first request Philadelphia to ground his circuit. Philadelphia will do this by turning the switch arm p to w, thus cutting off all source of current at Philadelphia by inserting the ground coil Gc between the polar relay and the ground in place of the pole changer and the dynamos. Then the Scranton office will ground his set by turning the switch *H* to *r*, thus cutting off the battery at the home end. Now, with all source of current cut off, Scranton will adjust the polar-relay armature until it will remain against either stop, or move with equal force from the middle position toward one side or the other. This adjustment, called *centering the armature of the polar relay*, is to make the pull due to the permanent magnetism equal on each side.

52. Obtaining Resistance Balance.—Having centered the armature, the home battery will be turned on, in this case by turning the switch *H* to *p*, Fig. 19. If there is now more current in one winding of the differentially wound polar relay than in the other, the armature will be held more firmly against one contact point than against the other, which must be overcome by adjusting the amount of resistance in the artificial line by changing the plugs in the rheostat *Rh* until the armature will again remain against either contact point, or move with equal force toward one side or the other from the middle position, as before. When this is done the resistance of the line and artificial circuits are equal. This adjustment is called the *resistance balance*. Although this is usually the case, still strictly speaking, it is not necessarily the resistances of the two circuits that are made equal, but, rather, it is the magnetizing effects of the line and the artificial line coils.

If the rheostat is incorrectly adjusted, the signals from the distant office may be too light in one position of the home key and too heavy, or *sticky*, in the reverse position. Hence, it is important to test and, if necessary, to alter the adjustment of the rheostat until the incoming signals are equally good whether the home key is open or closed. Furthermore, the incoming signals should still continue to be good when dots are being rapidly made on the home key. The rapid manipulation of the home key alone may not show that the rheostat was improperly adjusted. This method of obtaining a resistance balance should always be followed especially in wet weather and on poor wires.

53. Obtaining a Static Balance.—If the capacity of the artificial line does not balance that of the line, there will be a kick of the home-relay armature at the instant the home battery is reversed, due to opening or closing the home key. A kick indicates that the line and artificial line have not the same capacities, or that one charges and discharges more quickly than the other. To eliminate this kick, it is necessary to adjust the capacity of the condenser *C*, Fig. 19, or its point of connection with the rheostat *Rh*, by means of the plug *o* until the kick disappears. The best way to do this is to ask the distant office to cut in, that is, to shift the switch arm *p* from contact *w* to contact *v*, and to close his key K_1, Fig. 20. This will close the home (Scranton) polar relay *PR*, Fig. 19. If the kick does not appear when the relay contact is closed, it surely cannot cause trouble at any other time, for that is the actual position of the home-relay armature when the distant office is making a dot or dash and when the home-relay armature must remain closed, that is, in contact with its front stop to which the local battery is connected. Hence, with the distant key closed, adjust the capacity of condenser *C*, Fig. 19, and then, if necessary, adjust the position of the plug *o* in the rheostat so as to retard or hasten the discharge from the condenser, until the kick disappears entirely. This adjustment is called the *static balance*. The nearer the peg *o* is placed to the end of the rheostat that connects with the artificial coil of the relay, that is, the less resistance there is between peg *o* and the relay, the quicker will the condenser charge and discharge.

54. Adjustment of a Battery Pole Changer.—The proper adjustment of the pole changer is very essential to the successful operation of the system in which it is used. The clock-face pole changer, shown in Fig. 15, may be adjusted as follows: Adjust the lever *n* by means of the limit screw *o* and the one below it, which is not shown, so that it will have a play of $\frac{1}{32}$ inch, which is about the same as is ordinarily given to a sounder, care being taken that the armature cannot strike the iron cores. Then, by means of the screw *o*, reduce this play to $\frac{1}{64}$ inch; this will hold the movable contact *e* on the forward end of the lever in its middle position. Now raise the screw *c* until the spring *d* barely touches the contact *e*, being careful not to turn the screw *c* too far. Similarly, lower the screw *b* until the spring *a* barely touches the contact *e*. Finally, raise the screw *o* until the lever has its working play of $\frac{1}{32}$ inch. The contact *e* in moving from one extreme position to the other should momentarily, in about its middle position, touch one spring before parting from the other. If it leaves one before touching the other, the circuit will be momentarily opened. On the other hand, it must not remain in contact with both springs any longer than is absolutely necessary, because the battery is short-circuited from the instant *e* touches one spring until it parts from the other. This period during which the battery is short-circuited can be reduced almost to nothing by carefully adjusting the instrument. No difficulty should be experienced in adjusting the B. & O. pole changer, shown in Fig. 14, if the principle of this pole changer and the adjustment just explained are understood.

55. Peculiarities of Dynamo Pole Changers.—The dynamo walking-beam pole changer is apt to require more attention than any other one instrument in either the polar duplex or quadruplex system. The method of adjusting and caring for it is the same for both systems. The contact points cannot be adjusted as closely as those of the pole changer used with gravity batteries. The battery pole changer uses only one battery of 350 volts but the dynamo pole changer uses two dynamos of, say, 350 volts each, one positive and the other negative; therefore, with the dynamos there is a pressure of 700 volts tending to jump across the air gap between the contact points. As a result, the introduction of dirt or the slightest jar between these two points will aid the electromotive force to establish an arc that acts as a fair conductor for the current, which at once flows through the beam from one dynamo to the other. In the gravity-battery arrangement, the highest pressure that can be short-circuited is 350 volts.

With the pole changer properly adjusted there is a spark at the break, but this legitimate spark is not nearly so harmful as the arc that hangs on when the instrument is so adjusted as to break improperly.

The tension of the spring may be so great that when the magnet releases the armature, the lever will fly to the other contact with such momentum that it rebounds more or less, causing an arc to form at this insecure contact. An arc will also be formed if the lever is not promptly released. This inability to promptly release the lever may be due either to the trunnion being too tight or to the weak tension of the spring necessary when the local battery is too weak. The first may be remedied by properly adjusting the trunnion; the second, by strengthening the battery and increasing the tension of the spring.

56. Adjusting a Dynamo Pole Changer.—A dynamo pole changer may be properly adjusted in the following manner: First, be certain that the current through a 4-ohm pole changer is not less than 250 milliamperes. For fast work, a current of 275 milliamperes is not too strong. Then adjust the contact points so that the signals can scarcely be heard on the pole changer when sent on the key controlling it. Next adjust the tension of the spring so that the down stroke will be just a little heavier than the up stroke, and see that the trunnion is neither loose nor binding. The expert quadruplex attendant adjusts the pole changer almost entirely by sound, because sight adjustment, aside from the preliminaries, is very deceptive. When the pole changer has been adjusted to have minimum play, and gives at the same time low but distinct signals, the tendency to arc is reduced to a minimum.

With the pole changer adjusted to have a minimum play, a sounder is often connected in series with the pole-changer magnet and key in order that the operator may hear his own signals. When there is a sounder in series with the pole changer, it will be necessary to hold down the sounder lever while adjusting the pole changer in order to hear only the signals on the latter.

57. Incorrect Balancing of Polar Duplex.—Mr. Willis H. Jones, in the Telegraph Age, makes the following remarks concerning the way some operators balance the polar duplex:

"Many operators adjust the condenser while the armature of the home relay rests upon the back contact point, and seem to be satisfied when the kick can no longer be heard. They apparently forget that the sound of the kick will disappear with a less amount of static eliminated when the lever rests upon the back stop than when it rests upon the contact point, because in the former position the armature must cross the intervening space before it can produce a signal, while in the latter, it needs but make a start.

"Some operators believe that they are equally successful in centering the polar-relay armature by giving the armature a temporary bias in order to make it more sensitive, but no one will deny that by this plan the magnetic balance is practically destroyed. Of course an endeavor is made to replace the lever in its former position, but such an action is plainly mere guess-work. If there are any that doubt this statement, let them try the plan on a poor wire, and, after having recentered the lever, as they believe, again ground the circuit at each end. It will be found that the experiment may have to be repeated many times before the armature can be found sufficiently well centered to remain where placed without further adjustment.

"To make matters worse, after having destroyed the magnetic equilibrium of the main and artificial line on the displaced armature, frequently attempts are made to mend matters by readjusting the rheostat while the distant office writes.

"When the apparatus is finally considered to be balanced, what are the actual conditions under which the operator is expected to work? Simply this—a practically lopsided relay, and a false line balance. It may work satisfactorily at the start, but the margin is very small, and a slight change in the atmospheric conditions may necessitate another balance."

POSTAL TELEGRAPH-CABLE BATTERY DUPLEX

58. Theoretical Connections of Main Circuit.—The principle of the polar duplex operated by primary batteries as arranged by the Postal Telegraph-Cable Company is shown in Fig. 23. The pole changer *PC* consists of two ordinary relays *r* and *r'*, called *transmitter relays*. The two magnets of the relays are connected in series and are operated simultaneously by the one key *K*. When this key *K* is open, the negative terminal of the main-line battery *B* is connected to the wire *a* lead-

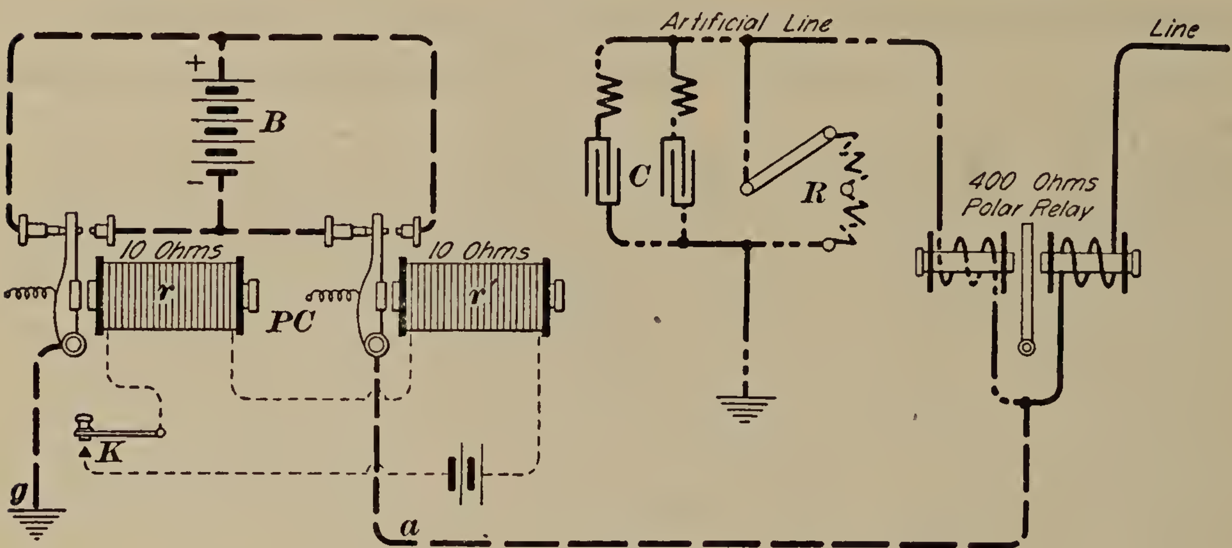
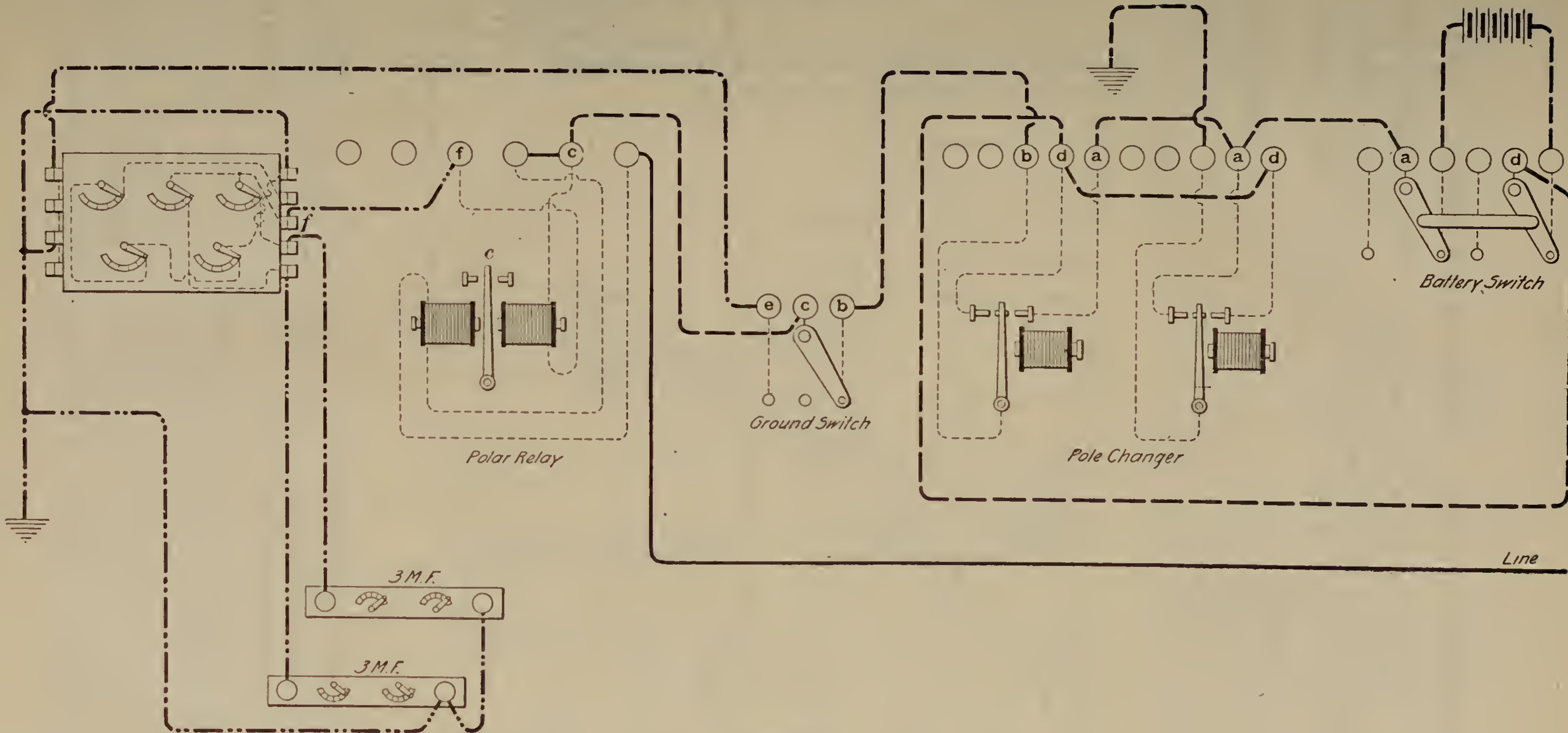


FIG. 23

ing to the middle of the differentially wound polar relay, while the positive terminal is connected to ground *g*. When the key *K* is closed the negative terminal is connected to the ground *g*, and the positive terminal of battery *B* is connected to the wire *a*. The rheostat *R* and condensers *C* constitute the artificial line. The local connections of the polar relay, which are not shown, are made in the usual manner.

59. Actual Connections of Main-Line Circuit.—The actual connections of the main-line circuits of the Postal Telegraph-Cable battery polar duplex are shown in Fig. 24. When turned to the right, as shown, the ground switch is in the operating position; it then connects the middle point *c* of the polar relay to the pole changer. When the ground switch is turned to the left, the center point *c* of the polar relay is connected to the ground for balancing the polar relay. Binding posts similarly lettered are connected together.



c
Polar Relay
Ground Switch
Pole Changer
Battery Switch
Line
3 M.F.
3 M.F.

FIG 24

HIGH-POTENTIAL, OR DYNAMO-LEAK, DUPLEX

60. Theoretical Connections.—The principle of the **high-potential** or **dynamo-leak, polar duplex** devised by Minor M. Davis for the Postal Telegraph-Cable Company is shown in Fig. 25.

In this circuit, there are two dynamos of about 385 volts each with their terminals of opposite polarity grounded. In series with each dynamo there is always at least one coil of 600 ohms

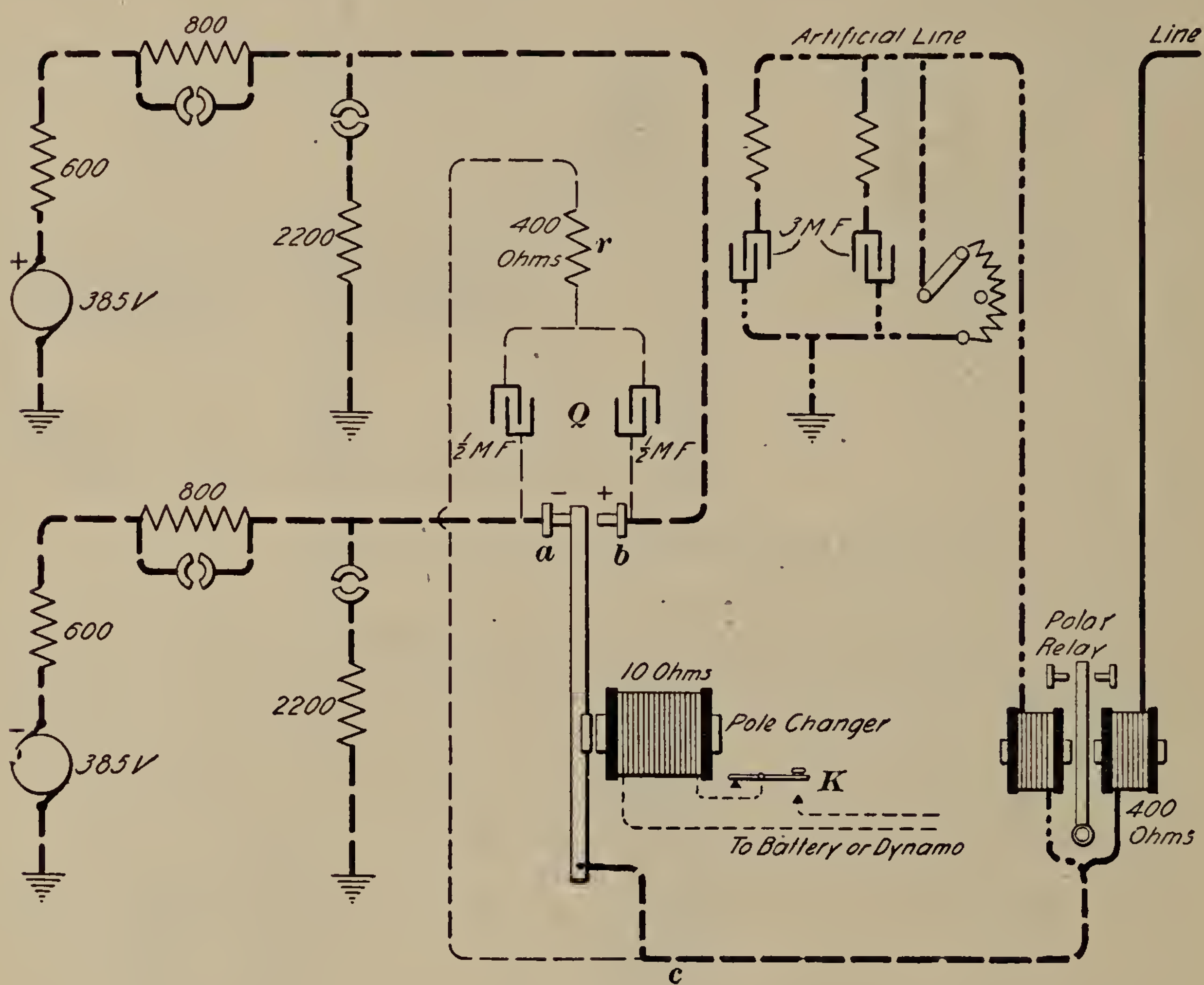


FIG. 25

to protect it from damage due to a possible short circuit. In series with each dynamo there is also a resistance of 800 ohms, which may be short circuited by a plug if a higher electromotive force is required. From each circuit a so-called leak resistance of 2,200 ohms is then connected to ground. This diverts some of the current to the ground and by increasing the fall of potential through the 600-ohm and 800-ohm coils, reduces the potential available at the pole-changer contacts.

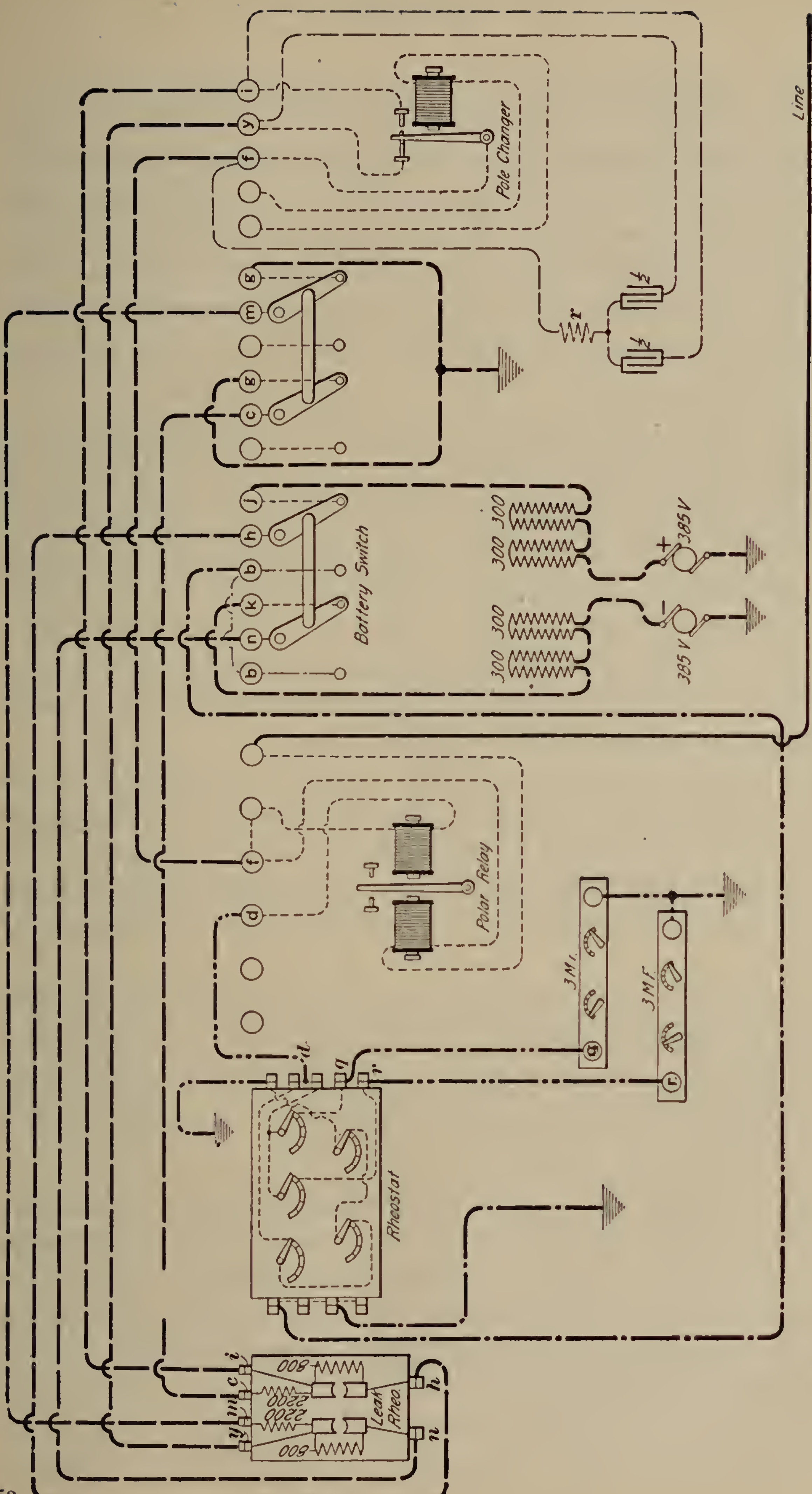

Line
Pole Changer
Battery Switch
300 300
300 300
300 300
+ 385 V
− 385 V
Polar Relay
3 MF.
3 MF.
Rheostat
800
2200
2200
800
Leak Rheo.

FIG. 26

This arrangement enables both long and short lines to be worked duplex in offices where it is not economical to instal special low voltage dynamos for the short lines, but where the high-potential dynamos installed for the regular quadruplex sets may also be used for this duplex system. If it is desirable to increase the potential, or if a lower voltage dynamo is available, the 2,200-ohm leak resistance may be cut out by opening its circuit; also the 800-ohm coil may be cut out by short-circuiting it.

61. The total resistance between the dynamo and ground is $600+800+2{,}200=3{,}600$ ohms. The current through this ground circuit, neglecting the amount diverted through the line and artificial line, will be $\frac{385}{3600}$ and the fall of potential through the 2,200-ohm coil will be $\frac{385}{3600}\times 2{,}200=235$ volts. Hence, the voltage applied to points *a* and *b* is very nearly 235 volts when the 3,600 ohms is in the ground circuit. The voltage applied to points *a* and *b*, when the 800-ohm coil is short-circuited, is $\frac{385}{2800}\times 2{,}200 = 302$ volts.

At contact *a* there is always a negative potential of the same voltage as the positive potential at contact *b*. Normally, contact *a* is closed and a negative potential is applied to the wire *c* leading to the differentially wound polar relay. When the key *K* is closed an equal positive potential is applied to wire *c*.

A condenser *Q* is connected from each contact of the pole changer through a 400-ohm resistance *r* to the pivot end of the armature of the pole changer to reduce the sparking at the pole-changer contacts. The local circuit of the polar relay is connected in the usual manner.

62. Actual Connections of Main Circuit.—The actual connections of the main circuits of the dynamo-leak polar duplex is shown in Fig. 26. By means of the battery switch each dynamo and its 600-ohm resistance may be connected to or disconnected from the circuit. Binding posts similarly lettered are connected together.

IMPROVED POLAR DUPLEX SYSTEM

63. The Polar Relay.—The differentially-wound polar relay used by the Postal Telegraph-Cable Company has the permanent magnets mounted under the base of the instrument. Fig. 27, which is a side view, indicates the approximate positions of the permanent magnets, the iron cores of the electromagnets, and the armatures *a* in an assembled relay. Both the permanent magnets and the electromagnets are of the horseshoe form. There are two soft-iron armatures, one on each side of the relays. Each of the armatures extends from the gap between the permanent magnets to the gap between the electromagnets. The two armatures are mechanically connected and are pivoted at *b*.

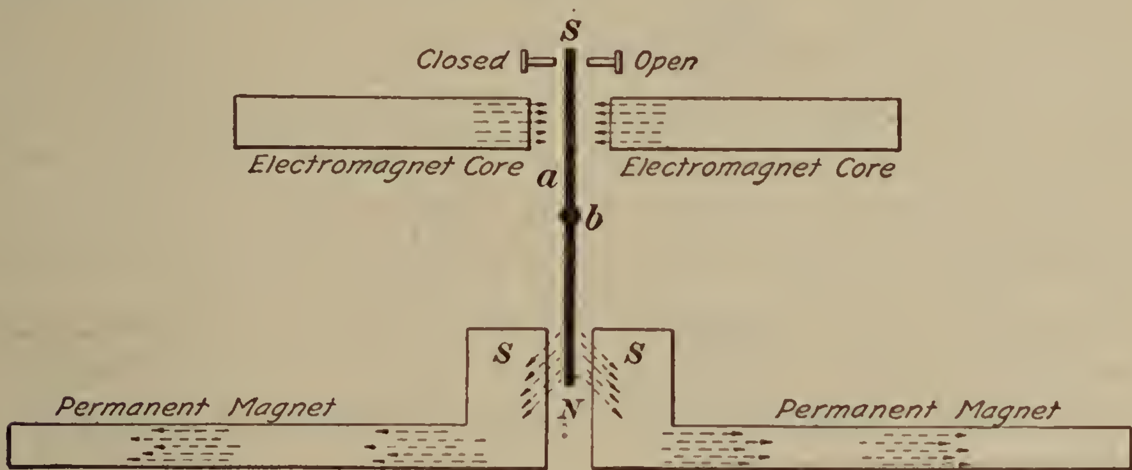


FIG. 27

A tongue is mounted between the armatures and moves with them so that in one position it makes a contact with the closed-stationary contact and in the other position it makes a contact with the open-stationary contact. The permanent magnets establish a north pole at the lower end of the armature shown in Fig. 27 and a south pole at its upper end. The armature at the other side has a south pole at its lower end and a north pole at its upper end.

The movement of the armature tongue forwards and backwards between the open- and closed-contact points is caused by changes in the polarity of the cores of the electromagnets, the changes being effected by the direction of the current through the windings on the cores. When the armature tongue has been moved to either of the two contact points, it will remain there until the direction of the current through the electromagnets is reversed. This is true even if the current in the electromagnets is of but momentary duration because the lower ends of the two armatures are held to the right or to the left by the attraction between the permanent magnets and the armatures.

64. Fig. 28 shows the connections of the Postal Telegraph-Cable Company's improved polar duplex system, including the magnet windings of the differential polar relays R and R_1. These relays are so wound that outgoing current from the home station does not magnetize the cores of the electromagnets of the home relay when there are equal currents in each set of windings. To have this condition, the ground switch at the distant station must be connected to the earth switch. The relays at each end of the line are so connected that the application of a negative current at the distant station causes the relay armature tongue at the home office to move to the closed-contact point c, while the application of positive current at the distant station causes the relay armature tongue at the home station to move to the open contact o. The local circuit containing the reading sounder S or S_1 and a local generator or a battery has one terminal connected to the closed-contact point c and the other terminal to the armature tongue. The relay armature tongue, therefore, controls the action of the reading sounder.

65. Batteries in Opposition.—It is important to gain a clear understanding of why both of the armatures of the polar relays at each station are attracted toward either the closed or the open contacts when the main-line batteries MB and MB_1 at each end of the line are in opposition. When the terminals of a wire are at equal potentials, no current will be established in the wire. When batteries or generators of the same voltage and like polarity are connected with the line, as in Fig. 28, the terminals of the line wire are at equal potentials. If the line circuit from station B is followed through the four magnet windings of relay R at station A,

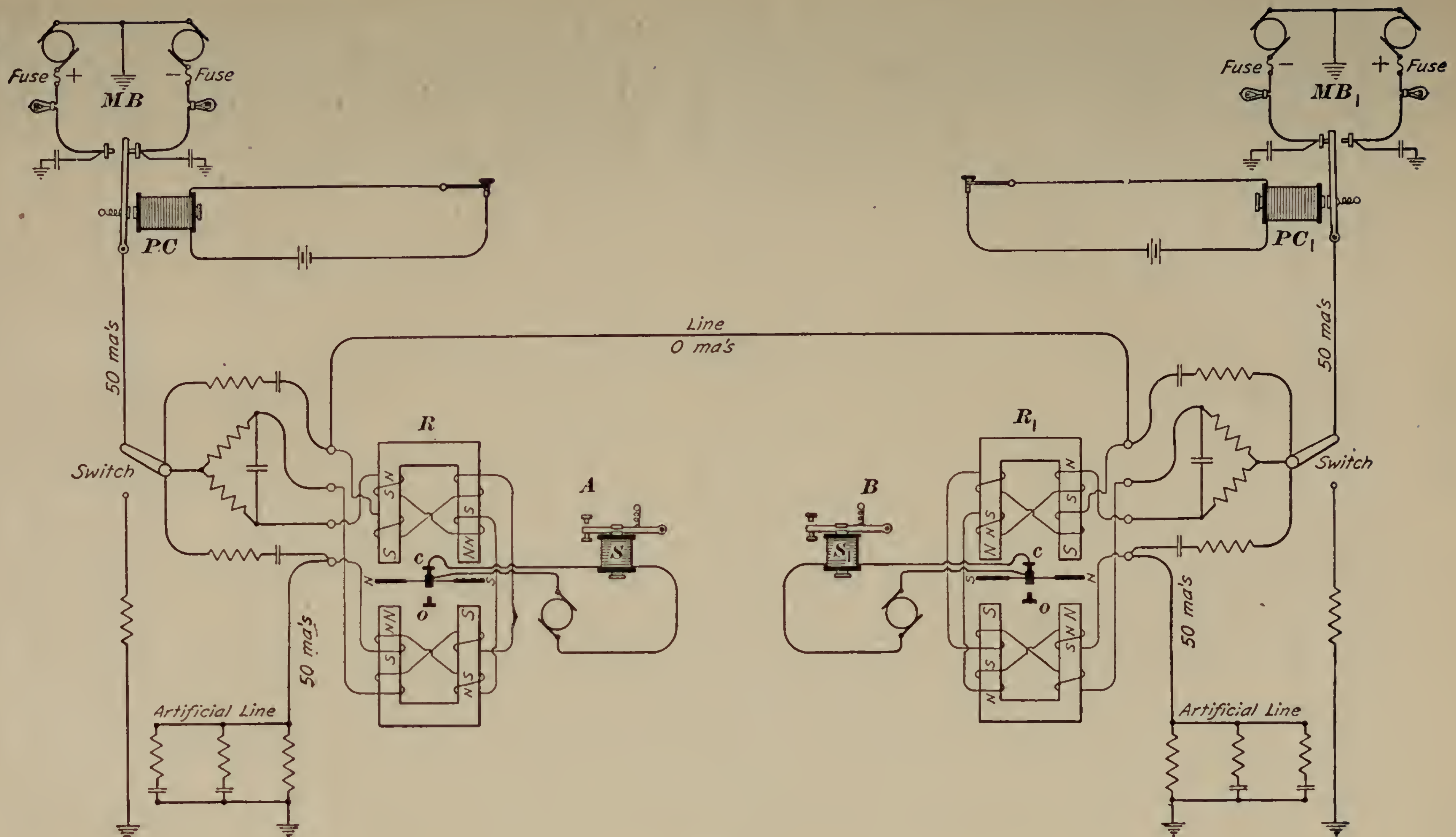

Fuse
+
−
Fuse
MB
PC
Fuse
−
+
Fuse
MB_1
PC_1
50 ma's
50 ma's
Line
0 ma's
Switch
Switch
R
R_1
A
B
S
S_1
c
o
c
o
50 ma's
50 ma's
Artificial Line
Artificial Line

Fig. 28

it may be noted that these coils are not marked as producing magnetism in the cores of the magnets. This signifies that not only is there no current in the main-line wire, but that there is no current in the windings of the relay which are in series with the line wire. The circuit at station *A* from the negative generator by way of the armature of pole changer *PC* leads to the earth contact through the four artificial-line windings of relay *R*. A current passes from the earth contact of the artificial line through the four windings of the relay that are in this circuit and through the generator to the ground at the upper brush. The result is that these four windings take on north and south polarity as marked, giving to the cores of the electromagnets north and south polarities as shown. The armatures of the relay will then be attracted toward the closed contact *c* and repelled from the open contact *o*. The diagram shows that all the current passing through the pole-changer aramature at each terminal station also passes through the artificial-line circuit at that station. Similar action occurs in relay R_1 when its armature tongue is moved against the closed contact *c*.

When the positive battery at each terminal station is connected to the line, the condition will be the same as that described in connection with Fig. 28, so far as the current in the main line is concerned. There will be no current in the main-line wire or in the magnet windings of the relays at each station in series with the line. The electromagnets of the polar relays are influenced only by currents in the windings in series with the artificial line. But, since the current is now in the opposite direction, the relay armatures will be attracted toward their open contacts *o*, the positive current having reversed the magnetism in the four windings in series with the artificial line.

66. Batteries in Series.—The next current combination to be considered is that in which a positive battery is connected to the line at station *A*, Fig. 29, and negative battery is connected to line at station *B*. If a current of 150 milliamperes passes through the pole-changer armature at

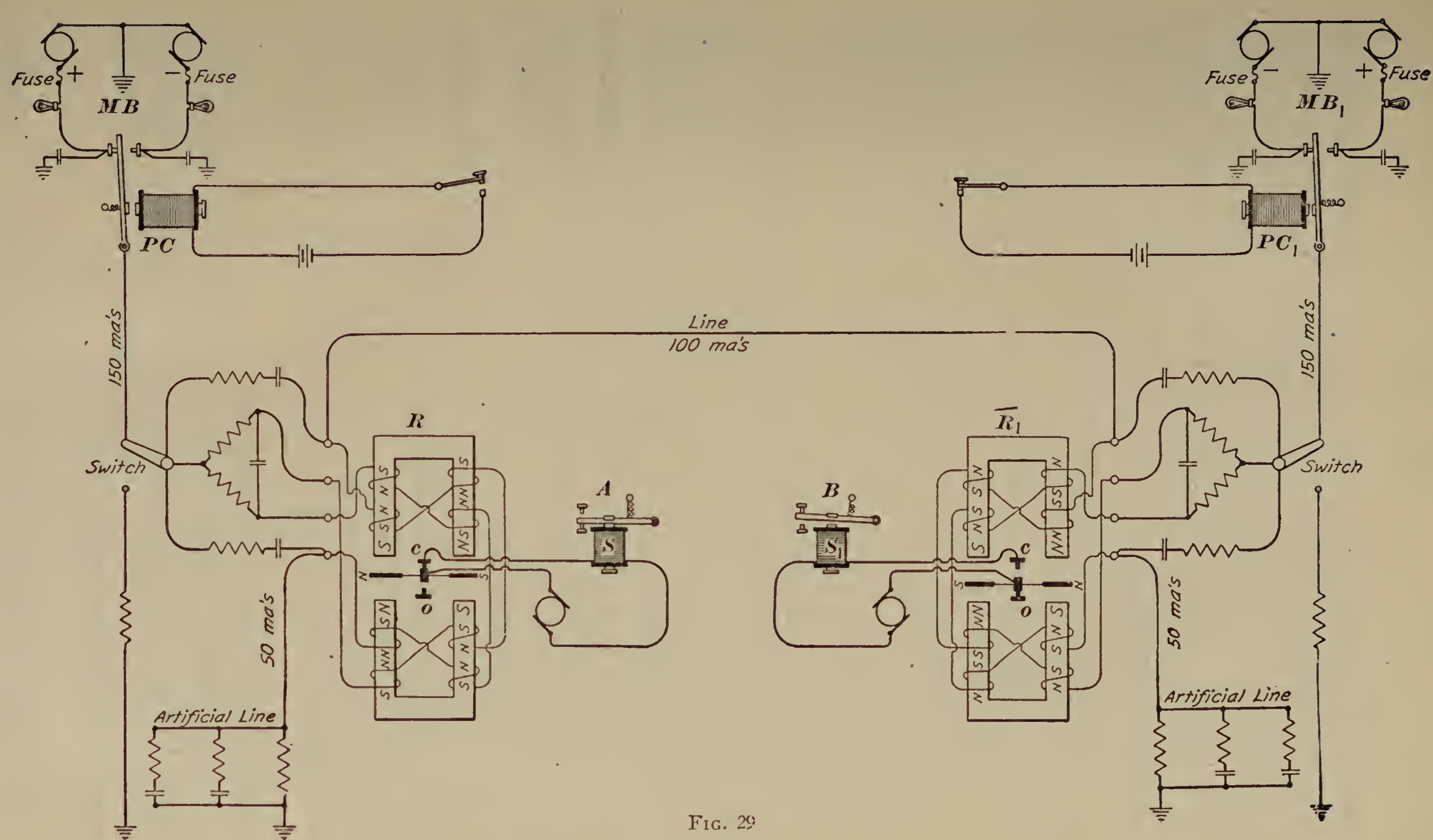

Fuse
+
−
Fuse
MB
PC
Fuse
−
+
Fuse
MB_1
PC_1
150 ma's
150 ma's
Line
100 ma's
Switch
Switch
R
$\overline{R_1}$
A
B
S
S_1
c
o
c
o
50 ma's
50 ma's
Artificial Line
Artificial Line

FIG. 29

each station, 50 milliamperes of this current will pass through the artificial-line circuit at each station and 100 milliamperes through the main-line circuit. The line wire and the relay windings in series with it will have a total current of 100 milliamperes, while each artificial line and its relay windings will have a current of 50 milliamperes, and each of the eight windings of each relay is producing magnetism as marked. Current from the negative battery at station *B* produces in the four windings in relay R_1, that are in series with the artificial line, the same polarities as when negative current is to line at both ends of the line, as shown in Fig. 28, but instead of no current being in the four windings of the relay that are in series with the main line, as in Fig. 28, current from the positive battery at station *A*, Fig. 29, now energizes the main-line windings of relay R_1.

It will be noted that the two generators are connected in series with reference to the main line, while the artificial lines obtain current from their respective generators. The voltage applied to the main line will be practically double that applied to the artificial-line circuit. The voltage applied to the artificial line will remain the same in value as in the case where the two batteries are in opposition. It follows, therefore, that the current in the main line, Fig. 29, will be twice as great as that in the artificial line.

The magnetic effect of the current in the main-line windings of each relay overcomes the magnetic effect of the current in the artificial-line windings. This results in the armature tongue of relay R_1 moving to the open-contact point *o* and the armature tongue of relay *R* moving to the closed-contact point *c*.

In case the positive battery is connected to line at station *B* and the negative battery is connected to line at station *A*, the armature tongue of relay R_1 will be against the closed-contact point *c* and the armature tongue of relay *R* will be against the open-contact point *o*.

67. Relay Shunt Circuit.—Fig. 30 shows the binding-post connections of the Postal Telegraph-Cable Company's

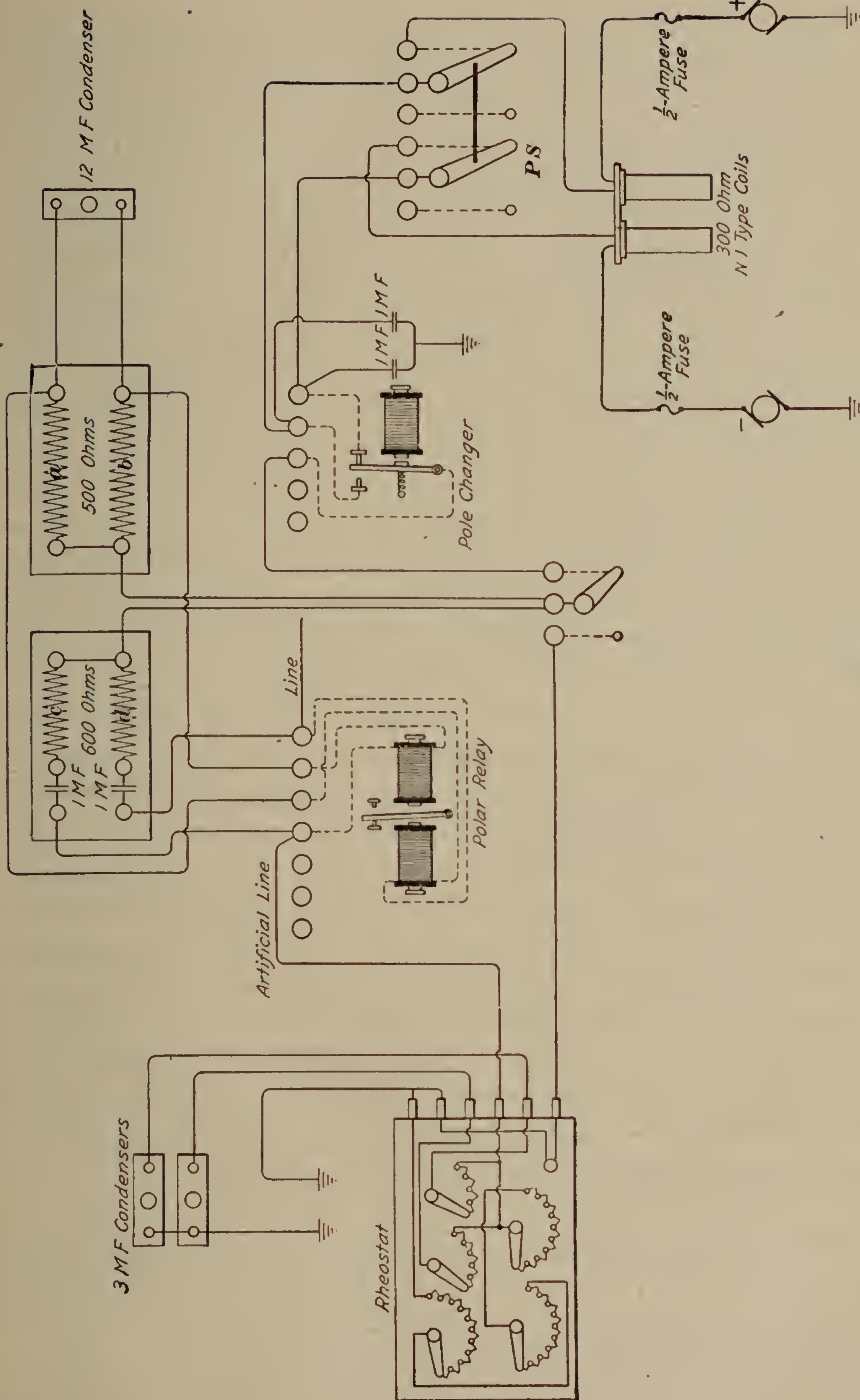

12 M F Condenser
500 Ohms
600 Ohms
1 M F
1 M F
Line
Artificial Line
Polar Relay
1 M F
1 M F
Pole Changer
PS
300 Ohm
N 1 Type Coils
½-Ampere Fuse
½-Ampere Fuse
+
-
3 M F Condensers
Rheostat

Fig. 30

duplex system. The junction point of two 500-ohm, non-inductive, resistance coils *a* and *b* is connected to the armature of the pole changer. The other end of coil *a* is connected to the binding post on the polar relay that leads to the coil that is in the main-line circuit; the other end of coil *b* is connected to the binding post on the polar relay that leads to the coil that is in the artificial-line circuit. A 12-microfarad condenser is connected across the terminals of coils *a* and *b*. The junction point of the two 600-ohm, non-inductive, resistance coils *c* and *d* is also connected to the armature of the pole changer. Coil *c* with a 1-microfarad condenser in series is connected to the artificial-line binding post on the polar relay, and coil *d* with a 1-microfarad condenser in series is connected to the main-line binding post on the polar relay. These circuits form shunts around the relay coils as indicated in Figs. 28 and 29.

The purpose of the two 500-ohm coils *a* and *b*, Fig. 30, is to introduce a larger proportion of the total line resistance between the relay and the earth connection near the generators than if these coils were omitted. This has a steadying effect on the balance between the main and the artificial lines. When the pole changer at the distant end of the line is operated, the 12-microfarad condenser connected in shunt across the terminals of coils *a* and *b* takes on a charge because of the difference of potential which exists between the ends of these coils due to unequal currents in them. The purpose of this condenser is to hasten the reversal of magnetism in the cores of the home relay when current reversals are received from the distant station. The condenser in discharging begins the action in the home-relay windings which action is completed by the application of current, either negative or positive, to the line by the distant pole changer.

68. In the ordinary duplex circuit, the armature of the home polar relay remains in contact with the closed-contact point while the armature of the pole changer at the distant station is in contact with its front stop, and until the pole-changer armature touches its back stop. With this arrangement, however, the 12-microfarad condenser causes a reversal of magnetism in the relay windings at the instant the armature of the pole changer at the distant station departs from either its front or back stop. The charge which the condenser has accumulated while the armature of the distant pole changer has been in contact with either pole of the battery will discharge through the windings of the home relay in a direction the same as that resulting from the succeeding opposite battery contact at the distant end. The current arriving from the distant station completes the operation already begun by the home condenser.

The two 600-ohm coils in series with 1-microfarad condensers connected around the relay coils present to incoming inductive disturbances a path to earth which does not lead through the coils of the relay. To some extent this makes the relay unresponsive to troublesome induced currents from alternating-current sources, and also electrostatic and electromagnetic induction from neighboring wires on the same pole lines. This duplex arrangement operates very rapidly and is of particular value where semi-automatic Morse transmitters are used by operators.

69. Regulating Resistance Units.—In Fig. 30 is shown a 300-ohm, non-inductive resistance coil in series with each generator lead, also a $\frac{1}{2}$-ampere fuse between the generator tap and the coil The fuse and the regulating resistance in each case are connected in circuit between the generator and the power switch *PS*. The power switch is mounted on a repeater table or a Morse multiplex table as a part of the apparatus of each duplex set. When the switch levers are thrown to the right, the main-line battery is applied to the contact points of the transmitting pole changer; when the levers are in a central position, the battery is disconnected. The purpose of the two unoccupied binding posts on the power switch is to provide a means of connecting leads from two additional generators which may be of higher or lower potential than the regular generators.

70. Purpose of Two Available Potentials in Duplex Working.—When main-line wires are clear and at a high state of insulation it is practicable to operate Morse duplexes over distances up to 500 miles with potentials of from 110 to 160 volts, but during rainy weather, or when a heavy fog extends over a considerable area, it is frequently found necessary to increase the battery potential on lines subjected to these adverse conditions in order to continue satisfactory working. In a given installation, therefore, it may be found that two of the binding posts of the power switch have positive and negative 110-volt potentials connected to them while the other two posts have positive and negative 240-volt potentials connected to them. For normal conditions, the levers of the power switch are thrown to the right, and when, in emergency, increased battery power is required, the levers are thrown to the left.

71. Spark Condensers.—In the Morse duplex system just described, a 1-microfarad condenser is connected between each of the contact points of the pole changer and the earth. The purpose of these condensers is to provide a discharge path to the ground for the excess currents which exist at the instant of make or break between the pole-changer armature and either its front or back contact. When a 240-volt negative potential is connected to the front post and a 240-volt positive potential is connected to the back post there is a difference of potential of 480 volts between the contact points, and as the armature lever moves backwards and forwards between these points in response to the operation of the transmitting key, there is danger of arcing unless provision is made to dissipate the surplus energy when contact is made or broken. There are several methods of reducing the degree of sparking that occurs at pole-changer contacts. The method illustrated in Fig. 30 is satisfactory when line potentials not higher than 300 volts are employed.

POSTAL RULES FOR BALANCING POLAR DUPLEX

72. The Postal Telegraph-Cable Company give the following rules for balancing their polar duplex systems:

1. Ask the distant station to ground.

2. Throw the ground switch (see Fig. 24) at the home station to the left.

3. Set the armature of the polar relay in the center, adjusting the magnets until the armature will remain on either contact or until it vibrates freely in response to the induced currents from the line. The magnets should not be too far from, nor too close to, the armature to give the best results. The correct distance varies according to the resistance of the circuit. The contact screws should be so adjusted that the armature is in a vertical position. The relay will not work well if the armature is not so arranged.

4. Throw the home station ground switch back to the right, thus placing the current on the line. Take a balance; that is, adjust the line resistance in the rheostat until the polar relay again acts as it did when the line was connected to the ground at both ends. This balance should be tried first with the home key open and then with it closed. If there is any variation in the resistance required to effect a balance, an average should be used.

5. Take a static balance in the following manner: Move back $\frac{1}{4}$ to $\frac{3}{8}$ inch the magnet of the polar relay which is on the side upon which the armature rests when the sounder circuit is open. Make dashes upon the key, which will show up the static kick. Adjust the condensers until this kick is removed. A variation in the adjustable resistances in the condenser circuits will sometimes aid in accomplishing this result, though it is usually found that when this resistance has been determined for any circuit that it will remain constant. After removing the kick, replace the magnet in its former position.

BALANCING A DIFFERENTIAL-POLAR DUPLEX SYSTEM WITH A BALANCE INDICATOR

73. The Balance Indicator.—The methods of balancing a duplex system previously described require a considerable amount of time to make the necessary determinations and adjustments. In order to speed up telegraph service, a method of balancing has been developed that allows accurate balance to be made in a minimum of time; therefore, the line need be out of regular service but for a short period. The *balance indicator*, or *balance milliammeter*, used in this method, indicates the direction and strength of the current passing through the instrument. The indicator is connected permanently in the circuit.

Fig. 31 shows one type of this instrument. The scale is graduated in divisions each representing a change of current of 5 milliamperes. The zero division mark is at the center and there is a possible reading of the scale of 175 milliamperes to the right or to the left.

The movable coil, to which the pointer is attached, is pivoted in position between the poles of a permanent magnet. When a current passes through the coil, magnetic poles are

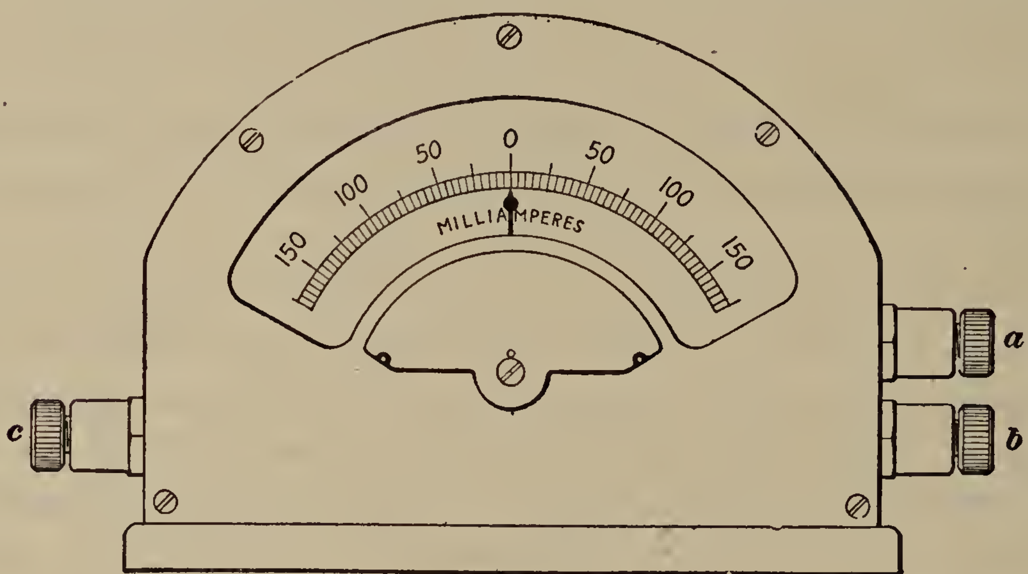


FIG. 31

formed at its ends and the attraction between these poles and the poles of the permanent magnet causes a rotation of the movable element. The pointer, Fig. 31, will indicate current values on either one side or the other of the zero mark on the scale, depending on the direction of the current through the movable coil.

Posts *a* and *b*, Figs. 31 and 32, form the terminals of two resistors that are connected end to end. The junction point of the resistors is connected to point *c*. The movable coil of the indicator is connected between posts *a* and *b*. Fig. 32 shows in a conventional manner the connections of the indicator to the coils of a polar relay. A current in the resistors between *a* and *c*, or *b* and *c* will cause a drop of potential along the resistor. If the resistances of these resistors and the currents in them are such that these drops in potential are unequal, a difference of potential will be established between points *a* and *b*, and current will pass through the movable coil from the point of higher potential to that of lower potential, thus causing a deflection of the pointer on the scale.

The resistors within the indicator are adjusted so that when the line and artificial line are properly balanced with the distant end grounded there will be no deflection of the pointer from the zero mark on the scale. When the negative terminal of the battery at the distant end is connected to the line, the current in the movable coil will cause a deflection of the pointer

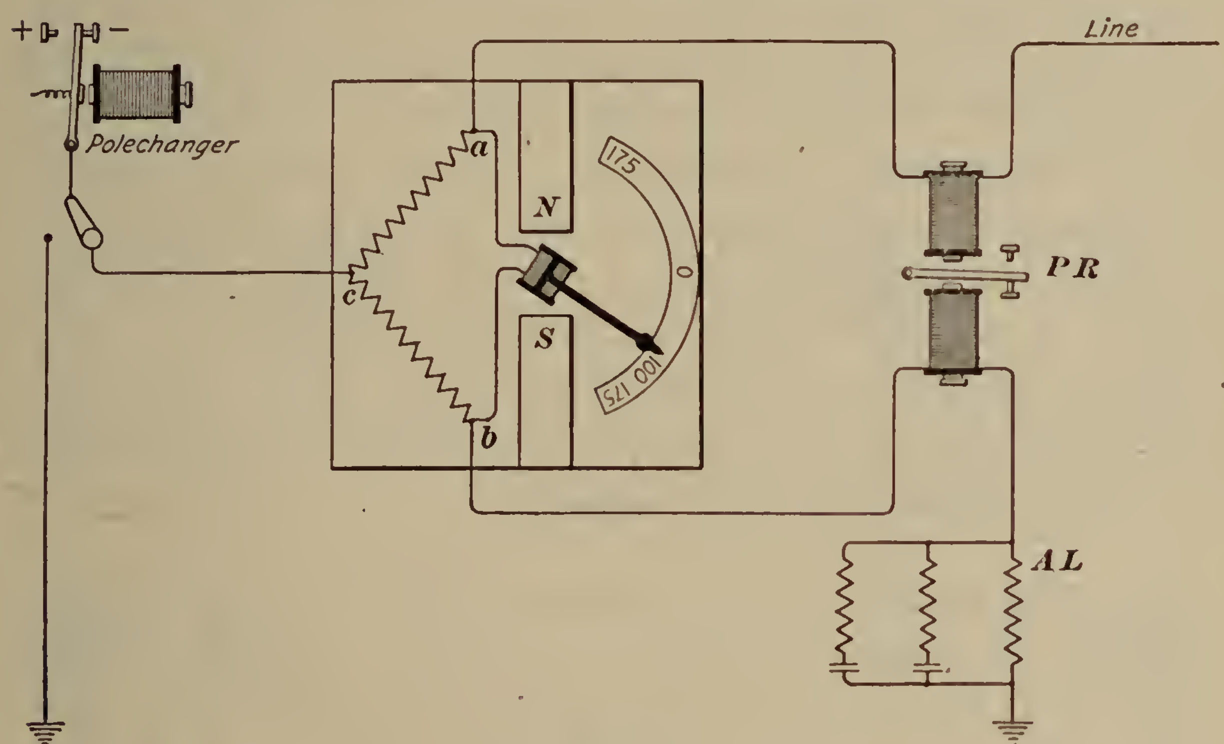


FIG. 32

on the right side of the scale. With the positive terminal of the battery at the distant station connected to the line, the current in the movable coil will cause a deflection of the pointer on the left side of the scale, irrespective of the position of the home pole changer.

74. Use of the Meter in Balancing.—The insertion of the balance milliammeter in a differential duplex circuit requires that the common terminal of the instrument be connected to the line binding post of the ground switch, while the other two terminals are connected respectively to the artificial-line and the main-line binding posts of the differential-polar relay of the set, the connections being the same as if an additional differential-polar relay were connected in the circuit.

To obtain an *ohmic balance* with a balance milliammeter, the following procedure should be followed: With the balancing switch grounded at the distant station, adjust the artificial-line rheostat until the pointer of the instrument indicates zero current. When the distant station applies negative current to the line, with the home-station negative battery also to line, the pointer of the balance milliammeter will be deflected to a certain point on the right of zero position. If there should be considerable movement of the pointer from its previous position when the home key is released, that is when positive battery is connected to line at the home station, the rheostat should be so adjusted that the pointer is deflected to a position midway between the two readings. In other words, should the pointer move farther away from zero when the home battery is reversed, the resistance of the rheostat should be increased; but if the pointer moves nearer zero, the resistance of the rheostat should be decreased until the pointer moves to a position where it is unaffected by current reversals caused by operating the home pole changer.

75. To obtain a *static balance*, order the distant station to throw the balancing switch to ground. Remove all resistance in series with the condensers of the artificial line at the home station, and apply the negative battery to the line. If, upon closing the home key, the pointer kicks to the left and returns to zero position, the capacity of the artificial line should be increased. If the pointer kicks to the right, the capacity of the artificial line should be decreased to a value where minimum movement of the pointer is observed when closing the home key. The resistances in series with the artificial-line condensers should then be adjusted until the pointer is unaffected by movements of the home key.

To obtain a static balance when positive battery is connected to line at the distant station, and the resistances in series with the condensers are cut out at the home station, it is necessary to take into consideration the fact that the pointer of the home balance milliammeter is at a point to the left of zero position. If upon closing the home key and applying negative current to the line, the pointer kicks farther away from zero, the capacity of the artificial line should be increased; if the pointer kicks toward zero, the capacity should be decreased. The resistances in series with the artificial-line condensers are then adjusted so that the pointer of the meter will not respond to the movements of the home key.

SUPERIMPOSED POLAR DUPLEX

76. To avoid interruption to service between large cities not too far separated from one another, as between New York and Philadelphia, or New York and Boston, underground

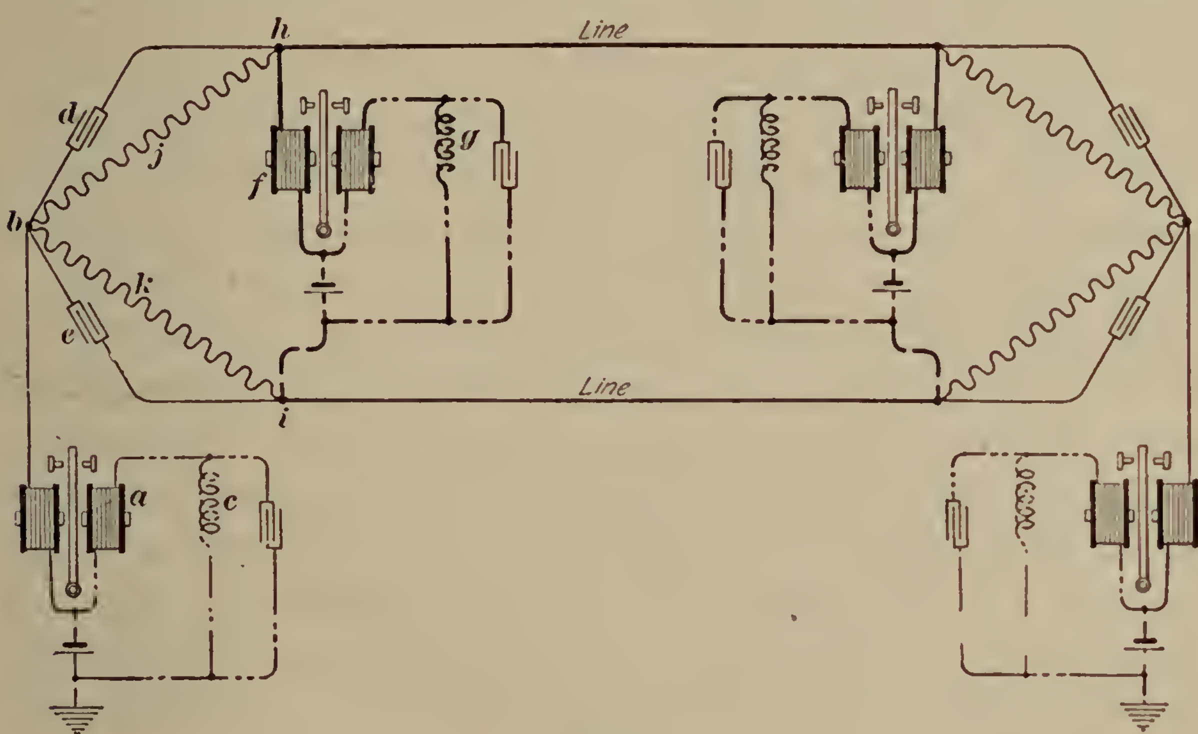


FIG. 33

cables for the entire distance are in use. To avoid disturbing other circuits in the same cable, it is necessary to use complete metallic circuits, that is a pair of evenly balanced cable wires for each circuit.

When a large number of wires are required on main routes, the capital cost of underground construction per mile of conductor is approximately the same as for overhead work, and when the greater freedom from interruption of the underground conductors, as compared with that of open wires, and also the probable longer life of the underground work is considered, there is much to encourage the rapid extension of the main underground network of telegraph wires.

To protect one pair of wires from induction from other pairs, each pair of wires in some telegraph cables are wrapped with a very thin sheet of metal, preferably iron. To make better use of such pairs, the English post-office telegraph department superimposes an ordinary hand-operated polar duplex on a pair of wires that is also used for a quadruplex or a Wheatstone or Hughes duplex by the arrangement shown in Fig. 33. There is bridged across the line wires from *h* to *i* a Wheatstone duplex or a quadruplex set *f* with its artificial line *g*. At *a* is the regular polar duplex with its artificial line *c*. Bridged across the line wires are also two non-inductive resistances *j* and *k* and two condensers *d* and *e*. The two line wires and resistances are connected in parallel from the point *b* and act as one conductor for the less rapidly fluctuating polar-duplex current, which does not seem to cause sufficient disturbance to prevent its use on all pairs in the same cable. The ground forms the return path for the regular polar-duplex current.

For lines under 149 miles (240 kilometers) in length, the resistances *j* and *k* each contain 3,000 ohms; for lines over 149 miles each resistance consists of 5,000 ohms. These resistances *j* and *k* are each shunted by condensers *d* and *e*, thereby increasing considerably the range of working of the polar-duplex sets. The capacity of the condensers *d* and *e* is 10 microfarads each for circuits over 149 miles in length, while for lines of less than 99 miles (160 kilometers) no such condensers are required.

DUPLEX TELEGRAPHY

(PART 2)

Serial 1504B — Edition 2

BRIDGE DUPLEX SYSTEM

GENERAL DESCRIPTION

1. The **bridge duplex system**, shown in Fig. 1, has four resistance arms with a relay at each end bridged across from the line to the artificial line. The four arms of the bridge are *a c*, *a d*, *d* G_1, and from *c* through the line and apparatus at the distant station to the ground G' and G_2. Included in these arms are four adjustable resistances M, M', N, and N' and the line and artificial lines. The relays R and R' are connected across the adjustable resistances. The *artificial lines* consist of the resistance boxes Rh and Rh' and the condensers C and C' which are connected to the grounds G_1 and G_2. The resistance of the artificial line at each end must be equal to the resistance of the line wire plus the resistance from the distant end of the line to the ground through the apparatus at the distant station. Usually the resistance of one arm *a c* is equal to that of the other *a d*. In any case, the following proportion must be satisfied: Resistance of *a c* : resistance of *a d* = line resistance + resistance from c' through all paths at right-hand station to grounds G' and G_2 : resistance of the artificial line $d\,G_1$. When this is the case, there is no difference of potential between the points *d* and *c*. A rheostat S is so arranged that, as the lever is turned upwards, resistance is taken out of one arm *a c* of tne bridge and is added to the other arm *a d*, and vice versa if the lever is moved in the other direction.

When the key of a continuity-preserving transmitter *K* is pressed down, the lever *o* lifts the lever *v* off the contact point *p*, momentarily short-circuiting the battery in order to avoid

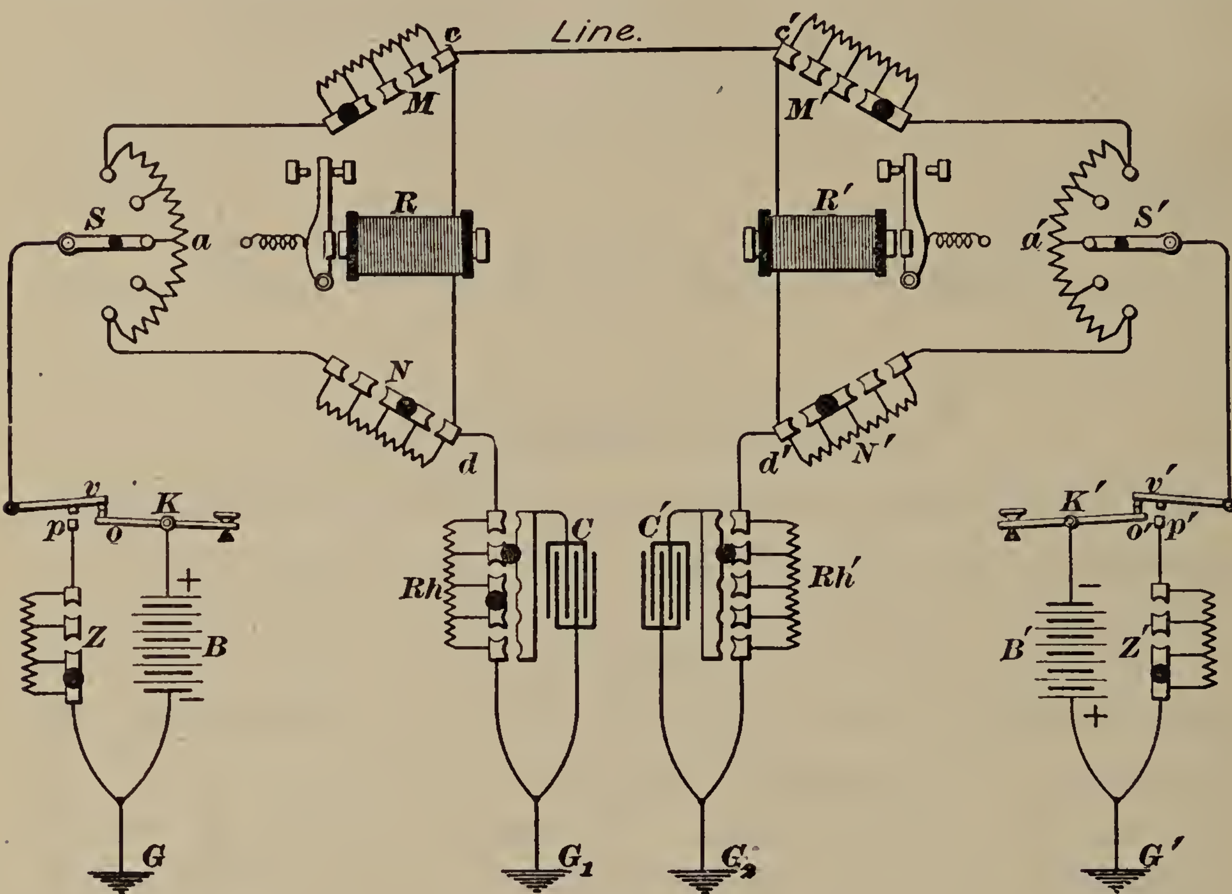


FIG. 1

opening the circuit between the ground *G* and the line. The resistance *Z* is adjusted to equal the internal resistance of the battery *B*. This resistance *Z*, the key *K*, and the battery *B* are arranged and used in the same manner as in the differential duplex. The apparatus and connections at the two stations are similar.

2. If one arm *a c* of the bridge bears the same relation to another arm *a d* that the circuit from *c* through the line and apparatus at the distant station to ground bears to the arm $d\ G_1$, the relay *R*, which is bridged across the points *c* and *d*, will not be affected by the outgoing current from the battery *B*, for the reason that there is no tendency for any current to flow in either direction between these points between which there is no difference of potential. If the key K' at the distant station is pressed down and the home key K is open, some current will pass along the line and ground and at the point c will divide, a part of it passing through and operating the home relay R because for this incoming current the points c and d are not at the same potential. The position of the home key K will in no wise affect the operation of the home relay R, because the position of the key K does not alter the resistance of the circuit between the point a and the ground G. Thus the relay at one station will be operated only by the key at the distant station.

3. Adjustment of Resistances.—Adjustment of resistances is made in arms $a\ c$ and $a\ d$, first by means of the resistance boxes M and N, and, finally, by the rheostat S. If the resistance from c through the line and apparatus at the distant station to the ground is 4,000 ohms, then a resistance of 1,000 ohms in the arm $a\ c$, 2,000 in the resistance box Rh, and 500 in the arm $a\ d$ will properly balance the bridge. The connection between the condenser C and the resistance box Rh should be adjusted until the artificial line charges and discharges in the same manner as the line, so that no momentary kick would be made by the relay.

4. Comparison Between Bridge and Differential Duplex.—The bridge duplex is superior to the differential duplex in that it requires less condenser capacity in the artificial line, and the resistances and condensers can be more readily adjusted to suit the varying conditions of the line. However, the bridge duplex is inferior to the differential duplex in that it requires more battery power to produce the same strength of current in the relay. This inferiority of the bridge duplex has excluded it from use on long land circuits. On short lines of low resistance, where an excessively high electromotive force will not be required and when batteries of low resistance can be used, it is preferable to the differential duplex, but it has not been generally considered preferable to the polar duplex. The bridge principle is used wherever submarine cables are duplexed; but, while the principle is the same, the apparatus used is quite different from that shown in Fig. 1. The bridge duplex, as applied to submarine cables, will be explained in connection with submarine telegraphy.

POLAR BRIDGE DUPLEX

5. Description.—In Fig. 2 is shown a bridge duplex system used by the American Telephone and Telegraph Company. This company terms it a **polar bridge duplex** because a polar relay is bridged between the line and artificial line. It should be remembered that practically all duplex, quadruplex, and repeater sets employed by this company must be suitable for use in connection with complete metallic telephone toll circuits. Consequently, their operation must produce no clicks or other disturbing noises in the telephones that may be connected across each end of the two wires forming a complete metallic circuit.

The line wire shown is one of two wires that form a complete metallic telephone toll-line circuit. The other telephone line wire may also be used for another duplex set. The apparatus shown may be applied to a single wire, or to a simplexed or composited line circuit. The terms simplex and composite, as used by telephone companies, are explained elsewhere. When there is to be transmission in one direction at a time only, this apparatus will operate over a circuit or combination of circuits that could not be used for full duplex service nor operated satisfactorily by single-line apparatus. When this duplex set operates in connection with both a single line and a duplexed section of a telegraph circuit, this company terms it a *duplex half repeater*. Each duplex set has a cam-lever switch P which enables the set to be used either as a duplex half repeater or for full duplex service. When the main lever of the pole changer rests against its back stop the extra spring levers touch neither the front stop nor the main lever, hence the spring levers are on open circuit.

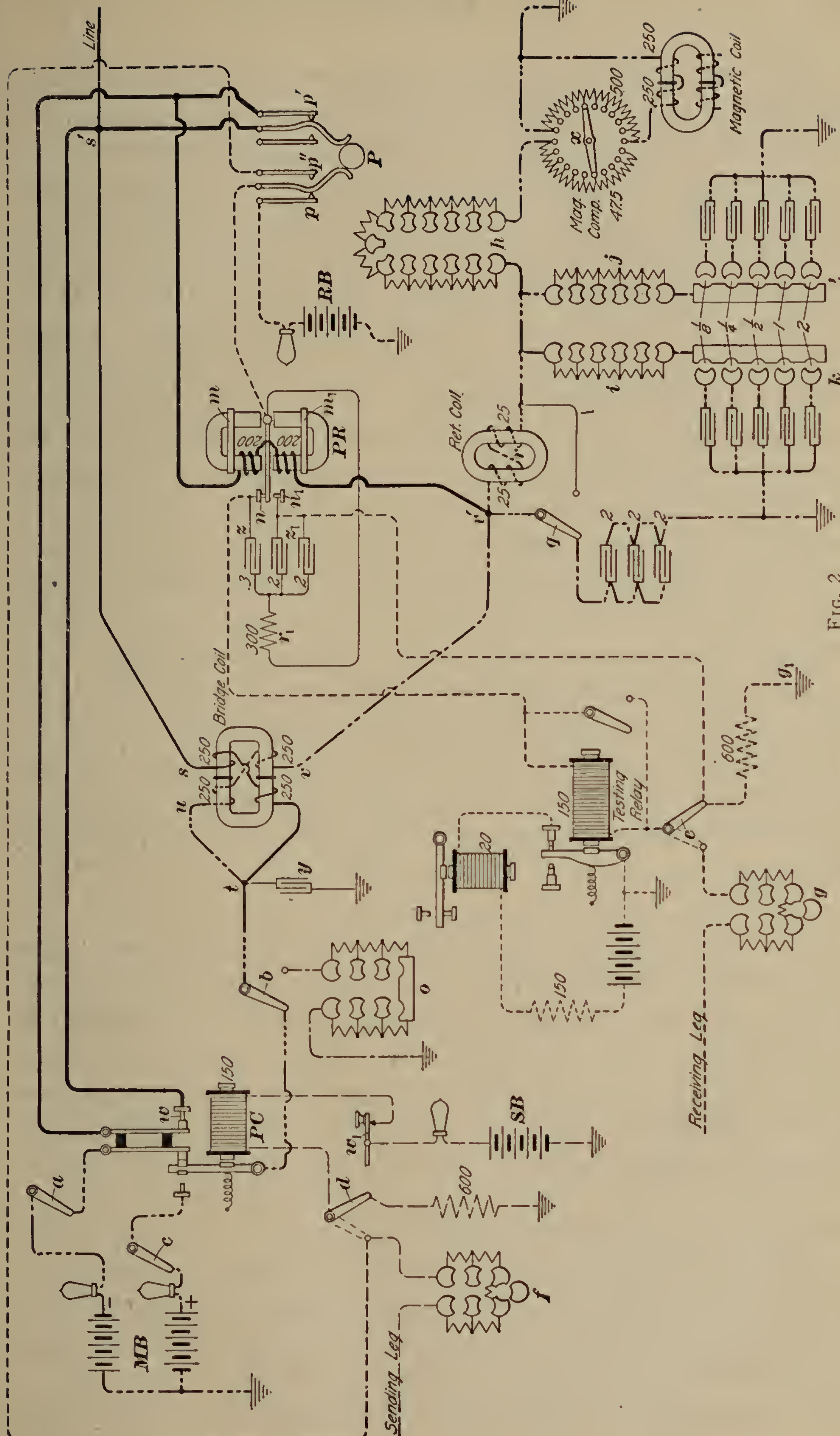

Line
Magnetic Coil
Mag. Comp.
RB
PR
Ret. Coil
Bridge Coil
Testing Relay
Receiving Leg
SB
PC
MB
Sending Leg

Fig. 2

6. Operation.—The polar bridge duplex system operates in very much the same manner as the bridge duplex just explained. The important differences consist in the use of a polar relay *PR* across the bridge in place of a neutral relay, a pole changer *PC* in place of a transmitter, an inductive non-adjustable bridge coil in place of non-inductive adjustable bridge coils, and inductive resistances in the artificial line in addition to the usual non-inductive resistances. A pole-changer *PC*, controlled by the key w_1 connects the point *t* to the negative terminal of one battery for sending dots and dashes and to the positive terminal of a similar battery for terminating the dots and dashes, and therefore for starting the spaces. This polarity should be retained on all sets for the sake of uniformity. Whatever current passes from the home main-line batteries *MB* to the point *t*, there divides equally through the line and artificial line and produces no difference of potential between the points s' and v' to affect the polar relay. An incoming current of either polarity passes from the line through the contact p' on the switch *P* (or when the set is used as a half repeater through contacts *w* on the pole changer *PC*), then through the polar-relay winding to point v', where it divides and passes to ground through the path of least resistance.

7. Rheostat and Switches.—The numbers placed opposite coils and condensers in Fig. 2 represent the resistances of the coils in ohms and the capacities of the condensers in microfarads. The resistances *f*, *g*, *o*, *h*, *i*, *j*, which are adjustable by pegs, are all located in one box, called a **combination quad rheostat.** They are shown separately to avoid a complicated-looking drawing, but the general shape of each set is retained so that there will be no difficulty in locating each one when it is assembled in the one box.

The switches *a*, *b*, and *c* are located on one slate base in the order named and the levers of *a* and *c* are fastened together so that one handle serves to turn both of them to the right or left. The middle lever *b* may be turned, however, to the right or left independently of the other levers *a* and *c*. All three arms are turned to the left while the set is in use either for full duplex or half-repeater service. When the arm *b* is turned to the right an adjustable resistance *o* is substituted for the main-battery circuit.

The switches *d* and *e* are mounted on one slate base and each lever may be turned independently of the other. However, both are turned to the left for half-repeater service and to the right or left for full duplex work.

The switch *q*, which is also mounted on a slate base, is turned to the left when this set is used on a composited wire. It then puts into the artificial line a non-inductively connected retardation coil *r* of 50 ohms and a capacity shunt to ground of 6 microfarads. This switch is turned to the right when the set is used on a single, or simplexed, line and then it cuts out of the artificial line both the condensers and the coil.

8. Bridge Coil.—To prevent an appreciable loss of the rapidly fluctuating telephone current flowing over the line wire, it is necessary to have no path of low inductance between this line wire and the ground side of the duplex set. Therefore, both the bridge coil and polar relay must possess considerable inductance. The polar-relay coils possess considerable inductance and a total resistance of 400 ohms. The bridge coil, which has a very high inductance and a total resistance of 1,000 ohms, has its coils so connected that all four are in series inductively from *s* through $t-u-v$. As these coils may be sent out incorrectly connected, each bridge coil should be tested when installed and the connections so made as to give a maximum inductance between *s* and *t*, between *u* and *v*, and finally from *s* through $t-u-v$. The successful operation of this duplex depends much on this coil being properly connected.

9. Magnetic Coil.—The magnetic coil in the artificial line should have the two windings on the same side connected in series so as to give maximum impedance. These windings, and those of other devices when connected together, may be tested for maximum or minimum impedance in the following manner, but the method applies particularly to this coil.

Connect a telegraph relay in series with a ringing or other generator producing an alternating current having a frequency of at least 20 cycles per second. The relay should be adjusted so that it will respond when the test circuit includes one winding of the magnetic coil. If both windings connected in series for maximum impedance are included in the test circuit, the relay will respond feebly or not at all, but if the windings are connected for minimum impedance, the relay will respond quickly.

10. Resistance in Artificial Line.—The resistance *h*, Fig. 2, in the artificial line may be varied in 10-ohm steps from 0 to 32,000 ohms. In the artificial line there are also the two windings of the magnetic coil; each winding has a resistance of 250 ohms and the two are connected in series in such a way as to give their maximum impedance. This impedance, which is connected at the ground end of the artificial line, compensates for such inductive effects as may reach the home polar relay from the 500-ohm inductive winding in the line side of the bridge coil at the distant set. Since that bridge winding is shunted to some extent by the polar relay in the same distant set, it is essential to use a shunt to the 500-ohm windings of the magnetic coil at this home station. A portion of the non-inductive resistance in the right-hand part of the magnetic compensator *x* is used for this purpose. As the arm *x* is turned counter-clockwise, the resistance in series with the magnetic coil is increased and the resistance in parallel is decreased.

11. In damp weather, the lower insulation resistance of the line requires less resistance in the artificial line rheostat *h* in order to balance this bridge duplex set. This causes more current to flow from each end into the line, nevertheless the effective current at each end is altered less by the opening and closing of the distant pole changer than in dry weather. Consequently there is less inductive disturbance on the home apparatus on account of the inductance of the distant bridge coil and polar relay. This smaller inductive disturbance is balanced by using a smaller non-inductive shunt in the magnetic compensator secured by turning the arm x counter-clockwise. Furthermore, after once securing a resistance balance by adjusting the artificial-line rheostat h, it is undesirable to again alter it when adjusting for inductance effects. Hence, the ten non-inductive resistances in each arm of the magnetic compensator (50 ohms per step in the right-hand side and mostly 5 ohms per step in the left-hand side), are so proportioned and arranged in connection with the 500 ohms in the magnetic coil, that moving the arm x does not appreciably affect the resistance from h to the ground.

By placing the arm x in a vertical position, the artificial line is opened. When in this position, a waste of current when the duplex is not in use and the line batteries have not been disconnected, is prevented; also the operator is able to determine whether this set is actually connected to a line wire.

12. Reducing Sparking.—The 1-microfarad condenser y, Fig. 2, reduces the sparking that would otherwise be troublesome at the main-line contact points of the pole changer PC. In emergencies, this condenser may be replaced by a 2-microfarad one without greatly affecting the operation of this duplex set. The receiving circuit may be traced from ground g_1 through the 600-ohm coil (or from the receiving leg through the adjustable resistance g) – switch e – 150-ohm testing relay – front contact n of the polar relay PR – contacts p of switch P – safety-resistance lamp – receiving battery RB to ground. When this circuit opens, the .3-microfarad condenser z and the 300-ohm resistance r_1 form a circuit across the gap produced at n, causing the condenser to receive a charge instead of producing a bad spark across the gap at n.

13. Adjustment of Pole Changer.—The directions for adjusting the pole changer state that it should have a medium air gap between armature and iron core, and a moderate to light retracting spring. The play of the armature should be only enough to prevent sticking at the contact points. When the set is used for duplex working, the switch P is put in the position shown, in which case the right-hand contacts are together, thereby permanently closing the circuit between the line and the polar relay and throwing out of use the supplementary contacts *w* by short-circuiting them at *p*′.

The supplementary contacts *w* should have very little play. With the switch *P* in the opposite position to that shown, the set is used as a duplex half repeater, and the supplementary contacts *w* open the main-line circuit of the polar relay whenever the pole changer of the same set is open.

14. Adjustment of Polar Relay.—The polar relay should have its armature set midway between the magnet poles with an air gap of about $\frac{1}{32}$ inch on each side. The movement of the armature between the stops should be no larger than is necessary for it to make clear breaks in its local circuit. When the set is used as a half repeater, the smaller the movement of the polar-relay armature, the less exact need be the adjustment of the pole changer; but the polar relay must have enough tendency to move to the front, or closed, side of its center position to insure the lever staying against its front stop *n*, Fig. 2, when the polar-relay coils are cut out of the main-line circuit by the opening of the supplementary contacts *w* on the pole changer. This bias is secured by moving the keeper m_1 on the lower permanent magnet toward its coil and allowing the keeper *m* on the upper permanent magnet to remain at the most distant point from its coil. In actual use the polar relay is provided with a switch on the base that allows either contact to be used as the closed contact in case the batteries at the distant station should be reversed. Such a switch will be is shown in Fig. 3.

15. Light or Heavy Signals.—If the received signals are too heavy either on account of the sending of the operator or on account of too low an adjustment of the distant pole changer, they can be made lighter by increasing the resistance in the balancing rheostat *h*. The signals are made heavier by decreasing this resistance. When using the set for full duplex work, the character of the signals may be varied by altering the bias of the polar relay.

BALANCING POLAR BRIDGE DUPLEX

16. Approximate Adjustment of Artificial Line. The following directions were issued for balancing the polar bridge duplex system by the A. T. & T. Company:

(1) Set the cam-lever switch *P* in position, as shown in Fig. 2, for full duplex operation.

(2) Make the resistance of the balancing rheostat *h* equal to the estimated resistance of the real line, plus 250 ohms, which is the approximate resistance* of the apparatus in the distant duplex set, less the resistance of the magnetic compensator at the home end, for this already forms part of the home artificial line, but is included in the 250 ohms allowed for the distant set.

(3) Estimate the line capacity at 1 microfarad for each 100 miles of open-wire circuit, or each 10 miles of cable circuit. The total capacity so estimated should be divided about equally between the two adjustable groups *k* and *l* of condensers in the artificial line, connecting about 200 ohms in series with one group and 1,000 ohms in series with the other.

17. Calling Distant Station.—Turn the three switch levers *a*, *b*, and *c* to the left and call the distant station. If the line insulation is very low, the estimated balance may be so far out that the distant end cannot break. Under such conditions it is well to ground between calls by turning the switch lever *b* to the right, thus removing the home batteries from the line and leaving the polar relay free to respond to signals from the distant end.

The resistance in the rheostat *o* should be equal to the resistance from the switch *b* to ground through either main-line batteries *MB*, which should be alike. The use of this resistance *o* prevents unbalancing the circuit for the distant station.

18. Resistance Balance.—Having secured communication with the distant operator, have him make signals. Cut

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* This estimate of the resistance of the distant duplex set is good enough for the purpose. Its exact calculation is not of sufficient importance to devote any space to it.

in the home main-line batteries and vary the resistance balance until the signals are just the same, whether the key w_1 is held open or closed.

19. Adjustment of Magnetic Compensator.—Set the magnetic compensator to suit weather conditions. If the insulation resistance of the line is low, cut out nearly all the magnetic coil by setting the lever x near the open (vertical) position; but if the line insulation is good or contains composite apparatus at an intermediate station, set it to include nearly its maximum resistance in the artificial line.

20. Static Balance.—Have the key at the distant end closed and move the keeper m on the closed contact side of the polar relay PR up to the coil. Make dots rapidly, trying different amounts of capacity in the adjustable condensers, until the dotting does not affect the polar relay. Then have the key at the distant end opened and repeat the last test, but with the positions of the keepers m, m_1 reversed. Finally, with both keepers close to the spools, have the distant end write and note if, by dotting rapidly at the home station, the incoming signals are broken up; if so, slight changes in the resistance in series with the condensers, in the magnetic compensator, or in capacity, will remove the disturbance. Sometimes one, two, or all three of these adjustments must be varied to get the best results. After obtaining a balance, return both keepers to the outer ends of the relay. Particular attention is called to the necessity for fast dotting when taking a static or magnetic balance. A balance that appears to be perfect under slow dotting will often be found unsatisfactory when the telegraph subscriber starts fast work.

21. Balancing for Half-Repeater Service.—When the set is to be used for half-repeater service, the cam-lever switch P should be placed in its position (inner contacts closed) for that service and the polar relay biased as described under Adjustment of Polar Relay. In this service the polar relay is only in circuit when the sender's key at the same station is closed, hence, it is only necessary in making a static balance to see that the home relay does not respond to the closing of the home key. Therefore, there is a wider margin for the operation of the set as a half repeater than as a full duplex.

22. Balancing to Distant Ground.—The heretofore customary method of taking a resistance balance with the distant end grounded should not be used. That method was quite satisfactory before the use of trolley systems which cause wide variation in earth potentials, but under present conditions it cannot be relied upon as fully as the method given.

23. Morse Disturbance on Telephone Circuit.—Owing to the high impedance of the terminal apparatus, this duplex worked with 120 volts will cause only about the same Morse disturbance in the telephone of a composited circuit as 60 volts with single Morse. To avoid interference between telegraph signals and telephone ringing currents, the special, high-frequency, telephone, ringing set designed for use on composite circuits should be used for telephone signaling. It is not of sufficient importance to describe here the rather complicated composite telephone-ringing circuit.

24. Operation as a Half Repeater.—When the polar bridge duplex is used as a half repeater, the switch P is placed in the position opposite to that shown, switches d and e, Fig. 2, are turned to the left, and the supplementary contacts w should have very little play. Supposing all circuits to be in normal conditions and that a space signal arrives over the duplex line, and that the receiving leg is extended through a line and the desired office to ground. The polar-relay armature will part from n, and the condenser z and resistance r_1 will then prevent bad sparking at n. The receiving leg will be opened at n, thereby opening the relay at the distant station on the receiving leg, also opening the testing relay and its reading sounder. As the lever parts from the front stop n, the condensers z_1 of 4 microfarads capacity and the 300-ohm resistance r_1 are connected in the circuit: $SB-w_1-PC-d-p''-$polar-relay lever$-r_1-z_1-$600-ohm resistance $-g_1$, thereby causing a charge to pass through the pole changer into the condensers which tides the pole changer over the break and prevents the release of its armature. When the polar-relay lever touches the back stop n_1, the pole-changer circuit is closed through the 600-ohm resistance to ground g_1, thereby preventing the opening of the polar-relay circuit, although the receiving leg has been opened at n. Furthermore, when the polar-relay lever touches contact n_1, the condensers z_1 and resistance r_1 are short-circuited. The resistance r_1 should never be less than 300 nor more than 500 ohms. When a signaling current arrives over the duplex line, all circuits are restored to their former condition, thereby sending a current out over the receiving leg; and as the polar-relay lever moves from n_1 to n, the condensers z_1 are again connected in the battery circuit and the charging of these condensers again tides the pole changer over the no-current period.

When the operator on the receiving leg sends he opens and closes the circuit through the receiving leg $-e-$ testing relay $-n$ $-$polar-relay lever $-p''-d-PC-w_1-SB$, thereby controlling the pole changer which repeats his signals into the duplex line. The supplementary contact w opens the circuit of the polar relay whenever the pole changer opens, thereby preventing the repetition of the signals back to the sending operator, which would cause confusion.

25. When used as a half repeater, the smaller the movement of the polar-relay armature between stops, the less exact need be the adjustment of the pole changer. In this class of service the polar relay must be given enough bias to insure the retention of the lever against its front, or closed, stop when the polar relay is cut out by the opening of the supplementary contacts w of the pole changer or repeating sounder where one is used.

When balancing for half-repeater service, the cam-lever switch P should be placed in its correct position (inner contact p'' closed) for such service and the polar relay biased in the same manner as when balancing this set for full duplex work. In half-repeater service, the polar relay is only in circuit when the sender's key w_1 is closed, hence it is only necessary, when securing a static balance, to see that the home relay does not respond to the closing of the home key. Therefore, there is a wider margin for its operation as a half repeater than there is in full duplex service. In other respects the balancing of this set for half-repeater service is the same as for full duplex work.

26. Single-Line and Half Repeaters.—The **Athearn single-line repeater** may be used with a duplex set for repeating messages arriving over the single line through this single-line repeater and the duplex apparatus into the duplex line, or for repeating messages from the duplex line into the single line. By such an arrangement, the duplex is reduced to a simplex system because it is only possible to send messages in one direction at a time through both the duplex and single-line repeater. It is not as simple an arrangement as a half-duplex repeater, but it is claimed that it permits the use of the duplex set without biasing the polar relay, which is especially convenient in cases of extremely low margin on a duplexed circuit where the polar relay would not operate if given a bias. It is also claimed that this arrangement will withstand a greater amount of inductive disturbance from single-phase alternating-current railroad circuits than a full duplex repeater. Single-line and half repeaters are combined by connecting to the sending leg of the duplex, through an ordinary key, relay, plug, and spring jack, the wire that would otherwise pass from the single-line repeater to one single line, say the west line; and by connecting to the receiving leg of the same duplex set, through a plug and spring jack, the wire that would otherwise pass from the single-line west relay to the battery. In the receiving and sending legs there are adjustable resistances by means of which the desired current may be secured.

27. Cutting Out Extra Test Relay.—When two or more testing relays come into the same circuit by any combination of duplex half repeaters, or of single-line repeaters, or combinations of the two, the magnets of all the testing, or control, relays but one should be cut out of the circuit by means of the short-circuiting switches provided on the base of each relay.

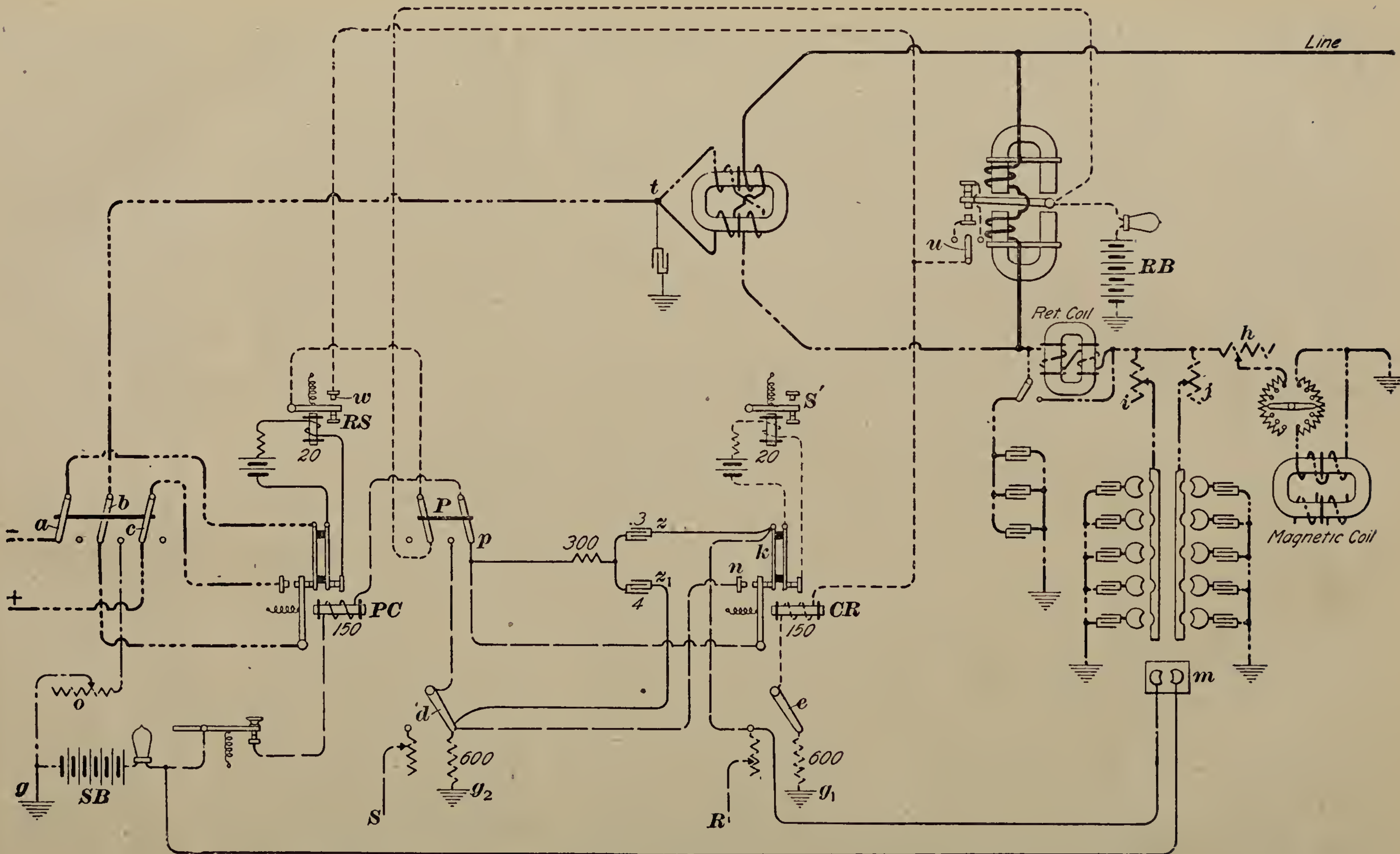
Line
RB
Ret. Coil
h
i
j
u
t
Magnetic Coil
m
RS
w
20
S'
20
a
b
c
P
p
300
3
z
z1
4
k
n
PC
150
CR
150
o
d
600
g2
e
600
g1
S
R'
g
SB
+

FIG. 3

This quickens the action of the circuit as a whole and increases the margin of adjustment on the pole changer. When two sets are used as half repeaters in each direction, the key of the eastern set should be used when writing for a station west and vice versa. On single-line repeaters use the key on the side next to the station making the request.

MODIFIED POLAR BRIDGE DUPLEX

28. In Fig. 3 is shown a later modification of the polar bridge duplex; it is called the **modified polar duplex** by the American Telephone and Telegraph Company, which uses it. The only change from the system just described is in the local circuits. In the modified arrangement, an additional relay CR, called a *control relay*, is used to control the receiving sounder S' and the circuits containing the .3-microfarad condenser z and the 4-microfarad condenser z_1. When the lever of the control relay rests against its back stop n, the condenser z_1 is practically short-circuited through the 300-ohm resistance and the lever and back stop n of the control relay. When the lever leaves this stop n, the condenser is charged by the battery SB through the coils of the pole changer PC – 300-ohm resistance – condenser z_1 – 600-ohm resistance – ground g_2, thereby holding the pole changer PC closed while the control-relay lever moves from its back to its front stop. The pole changer also controls a repeating sounder RS, which operates the supplementary contacts w. When the main levers of the pole changer and control relay rest against their back stops the extra spring-levers touch neither the front stops nor the main levers, and hence the spring-levers are on open circuit.

The switch P performs practically the same functions as the cam-lever switch P shown in Fig. 2. When the switches P, d, and e, Fig. 3, are turned to the left, the apparatus is connected for full duplex service. The sending and receiving legs S and R are connected through adjustable resistances to the sending-leg and receiving-leg jacks on the Morse board; from this they may be extended to any operator or telegraph subscriber's office.

The center lever *b* of the main-circuit switch operates independently of the levers *a* and *c*, which are controlled by one handle. When lever *b* is turned to the right, the point of the bridge is grounded through a resistance *o* that is adjusted to be equal to the resistance of the sending battery circuits.

29. Duplex Half Repeater.—When switches *P*, *d*, and *e*, Fig. 3, are turned to the right, the apparatus is arranged as a duplex half repeater. A short line that is worked single is connected through suitable jacks and plugs to the receiving leg *R*. If the single line is long, it first passes through a single-line repeater.

The repeating sounder *RS* simply shunts the local points of the polar relay when the pole changer *PC* is open. It thereby eliminates any kick of the polar relay due to the pole changer that might be produced when the line is open in case the set is a little out of balance or biased a little for some special reason. The repeating sounder also quickens the break by allowing the first sign of an open circuit on the single line that is connected to the receiving leg *R* to let the pole changer *PC* open. The opening of the pole changer *PC* opens the repeating sounder *RS* and thereby closes the shunt circuit around the polar-relay points. Closing this circuit holds the control relay *CR* closed and allows the pole changer to open firmly.

30. Operation of Duplex Half Repeater.—When no signal is arriving over the duplex line, the lever of the control relay *CR*, Fig. 3, rests against its back stop *n*. The single line coming to *R* is then open at *k* and the pole changer *PC* is in the closed circuit *g*–*SB*–*PC*–contact *p*–control-relay lever–back stop *n*–600-ohm resistance–g_2. When a signal arrives over the duplex line, the control relay lever moves to its front stop, thereby closing the circuit *g*–*SB*–*PC*–*p*–lever of control relay–back spring *k*–receiving leg *R* to the single line. Thus the single line has a current sent through it and the pole changer is also held closed. The 4-microfarad condenser z_1, by having the short circuit (from *p* through the lever of the control relay and contact *n* to *d*) around it opened at *n* receives a charge and so prevents the pole changer from opening while the control-relay lever moves from the front to the back stop n. When the lever touches k the .3-microfarad condenser z is simply short-circuited. Thus, the pole changer PC remains closed for any position of the control relay CR, thereby preventing the signals arriving over the duplex line from being repeated back over the same line. In this manner messages arriving over the duplex line are repeated into the single line.

31. The polar-relay lever normally rests against the stop that keeps the circuit g_1 – 600-ohm resistance – switch e – CR – switch u – polar-relay contact and lever – receiving battery RB to ground closed. If the distant battery should be reversed, thereby holding the polar-relay lever against the other contact, it is merely necessary to shift the switch-lever u to the other contact. The control relay CR, and hence also the pole changer, are consequently both normally closed.

When the operator on the single-line R desires to send, he first opens his key, thereby opening the circuit g – SB – PC – p – lever of control relay – spring k – receiving leg R – single line – distant office – ground. This connects the point t of the bridge to the positive instead of to the negative battery and hence causes the distant polar relay to open its local control-relay circuit and therefore also opens the circuit of the distant local reading sounder, corresponding to S'. When the single-line operator closes his key, the circuit just traced is closed and therefore the pole changer PC is closed and the distant polar relay closes its local control-relay and reading-sounder circuits. The half-repeater arrangement really reduces the set to a simplex system, but it gives better service than the Athearn single-line repeater and can be used when it would not work satisfactorily as a full duplex.

COMBINATIONS OF HALF REPEATERS, SINGLE-LINE REPEATERS, AND MORSE SETS

32. Full and Half-Repeater Sets Repeating Into Similar Sets.—If it is desired to make one duplex set repeat into another duplex set, the receiving leg of one set is connected to the sending leg of the other set and the sending leg of the first is connected to the receiving leg of the second set. With such connections messages may be repeated in both directions at the same time. If it is desired to use two sets as half repeaters for repeating from the first set into the second or vice versa, but not both ways at the same time, the two receiving legs are connected together. Messages received on the first set control the pole changer of the second set and vice versa at different times but not simultaneously.

33. Peg Switch.—When two sets are working together as half repeaters, with or without a single-line repeater between, the peg switch is useful. For example, imagine that two duplex half-repeater sets and an Athearn single-line repeater at Scranton connected together as follows: The receiving leg of one half-repeater set is connected to the single-repeater line wire that would otherwise go east and this same circuit after passing through the east relay of the single-line repeater (instead of going to battery and ground) is connected to the receiving leg of the second half-repeater set. The remaining single-repeater line is extended to Harrisburg; one duplex line goes to New York and the other to Buffalo. Then, messages arriving over one half-repeater set will be repeated into the single line by the single-line repeater and through the other half-repeater set into its line, and vice versa; furthermore, the operator at Harrisburg can send and have his messages repeated through the single-line repeater and both half-repeater sets to New York and Buffalo. The battery taps must be connected to opposite terminals of the sending batteries of the two half sets. If the duplexed line running to Buffalo fails, the repeater operator immediately throws the double switch *P*, Fig. 3, on the Buffalo set to the left and inserts a peg in the peg switch *m*. This peg allows current from the battery in the sending tap of the Buffalo set to hold closed the local circuit from the New York set through the single set to Harrisburg and Harrisburg may work with New York while the Buffalo line is being independently patched. This arrangement, of course, compels the sending battery in the Buffalo set to supply current for its own pole changer and also through the receiving leg and the pole changer of the New York set to the opposite terminal of the New York sending battery. The lamp in the Buffalo sending-battery circuit must be low enough in resistance to prevent any interference between the two parallel circuits. If too much current flows normally through the sending leg due to this small lamp resistance, it is regulated by special resistances provided for this purpose in the regular artificial-line-rheostat box. Thus, by means of the peg switch, any leg of a circuit going in several directions through half-repeater sets may be cut off without opening the local circuit into which they all repeat, while the defective leg is being tested out and properly connected or the line wire patched. Duplex half repeaters are being used in practically all the American Telephone and Telegraph Company's leased single lines on account of the great gain in efficiency over the single-line Athearn repeater.

34. Combinations of Half Repeaters and Morse Sets. An arrangement giving excellent service and considerably used by the American Telephone and Telegraph Company consists in looping an intermediate telegraph subscriber having a single Morse set directly in the line between two duplex half repeaters. For example, a wire duplexed direct from Pittsburg to Chicago with half repeaters at each end may have a telegraph subscriber at Columbus connected in series with the duplexed line. At one end of the main line the main batteries are reversed and at the opposite end the local contacts of the polar relay are reversed. When both pole changers are closed, the main line is connected to negative battery at one end and positive battery at the other end, which closes the intermediate relay and both polar relays. If the pole changer at either end is opened, batteries of like polarity are connected to each end of the line; the intermediate relay then opens because practically no current is present in the line and both polar relays open because they have been properly biased to do so. Should the intermediate subscriber open his key while all relays are closed, he opens the line and an open line unbalances each half-duplex set so that the duplex relays are both opened.

35. Another arrangement where it is desired to use a duplexed line to a small office which is not supplied with duplex apparatus consists in equipping one end with a duplex half-repeater and the small-office end with a single Morse set. The two main batteries at the half repeater and the single-line battery at the other end are arranged so that when the pole-changer key is closed, opposite battery polarities are connected at the two end stations. The polar relay is unbalanced and opened when the Morse set key is opened, and the opening of the pole-changer key puts battery terminals of like polarity to both ends of the line, and hence opens both the Morse set and the polar relays. While this does not give quite as good service as a wire equipped with duplex apparatus at both ends, it is much better than a single-line equipment, as it requires less adjustment of the Morse set in bad weather, as the duplex batteries can be adjusted to just neutralize the single-set battery, thereby enabling a low-adjusted Morse relay to be distinctly opened.

ADDITIONAL DATA ON BRIDGE DUPLEX SYSTEMS

BRIDGE DUPLEX WITH ONE GENERATOR AT EACH END OF THE CIRCUIT

36. Fig. 4 indicates the theoretical circuit connections for a single-current bridge duplex system using only one generator G or G_1 at each end of the circuit and a single-line Morse relay R or R_1 connected across the bridge arms at each terminal station. A transmitter T or T_1 serves to connect the points P or P_1 of the bridge with either the positive ter-

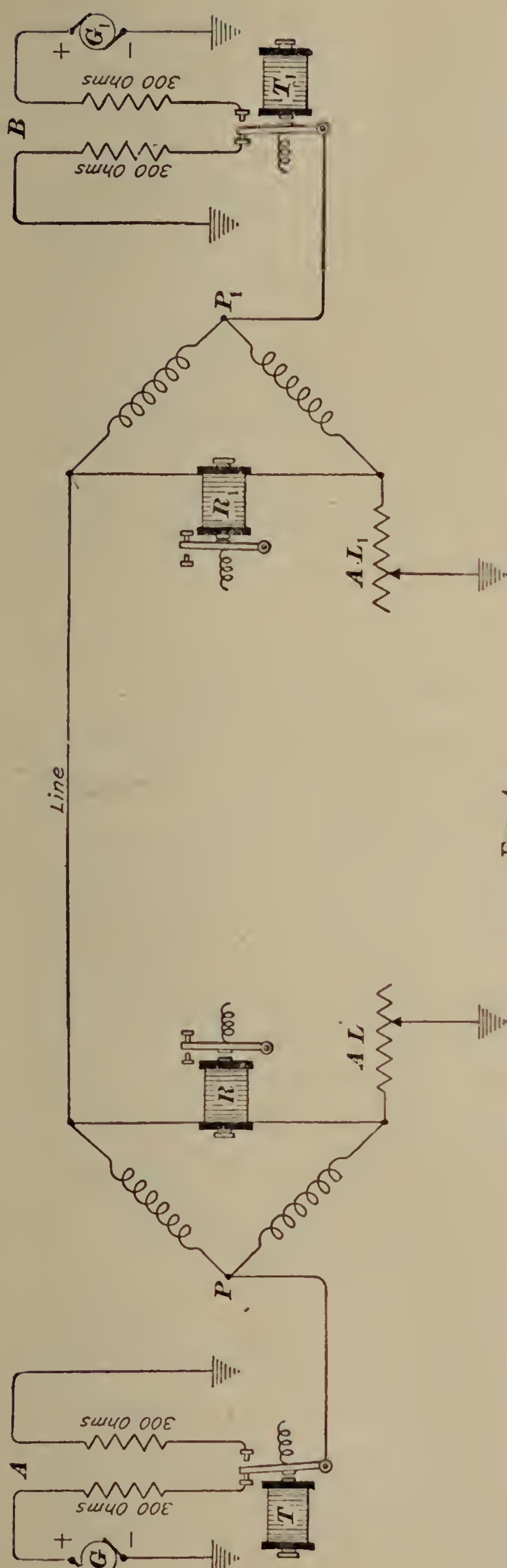

Fig. 4

minal of a generator or to a ground. In general, Figs. 1 and 4 are similar, but differ in certain details of equipment.

When the system is balanced, outgoing current from transmitter *T* at station *A* will not affect relay *R*, but will actuate relay R_1 at station *B* for the reasons stated in connection with Fig. 1. The relay at one station will be operated only by the key connected to the transmitter at the other station.

When the transmitter armature at each terminal station is in contact with its back stop, the ends of the line are grounded through the resistance coils and as the battery is disconnected from the line at both ends there is no current in either the main or artificial line and consequently the armatures of the respective relays are withdrawn by their retractile springs into contact with their back stops. Both ends of the system are, however, grounded through the artificial lines *AL* and AL_1.

This method of duplexing is satisfactory on lines not subject to induced currents from neighboring telegraph lines or from electric light or power circuits. The fact that there are continually recurring periods when the operating generators are disconnected from the line and the system is grounded at both ends through the artificial line, subjects the relays to the effects of induced currents which may cause false signals in the relays. A double-current system which provides both positive and negative main-line potentials at each end of the circuit is not subject to the same extent to disturbances from induced currents from neighboring lines, for the reason that either positive or negative battery at one end or the other is connected to the line except in those occasional brief instants when the armatures of both pole changers are midway between their marking and spacing contact points.

DOUBLE-CURRENT BRIDGE DUPLEX

37. Connections.—Fig. 5 indicates the theoretical connections of the double-current bridge duplex system as used by the Western Union Telegraph Company and on various railroad systems. The single-line Morse relay *R*, Fig. 4, is replaced by a polar relay *PR*, Fig. 5, at each terminal station. Two generators G_1 and G_2 are used at terminal station *A* and two generators G_3 and G_4 at station *B* instead of one generator and a resistance to ground at each station. The positive terminal of a generator is connected to the line when the armature of the pole changer *PC* or PC_1 is open, or resting against its spacing contact, and the negative terminal of another generator is connected to the line when the armature of the pole changer is closed, or resting against its marking contact.

The polar relay used in duplex systems differs from a single-line relay in that a current passing through it in one direction causes the armature to move to one contact, while a current in the opposite direction causes the armature to move to the other contact. The single-line relay closes its armature when current of sufficient strength in either direction passes through its coil and releases its armature when the current ceases or is considerably reduced in strength.

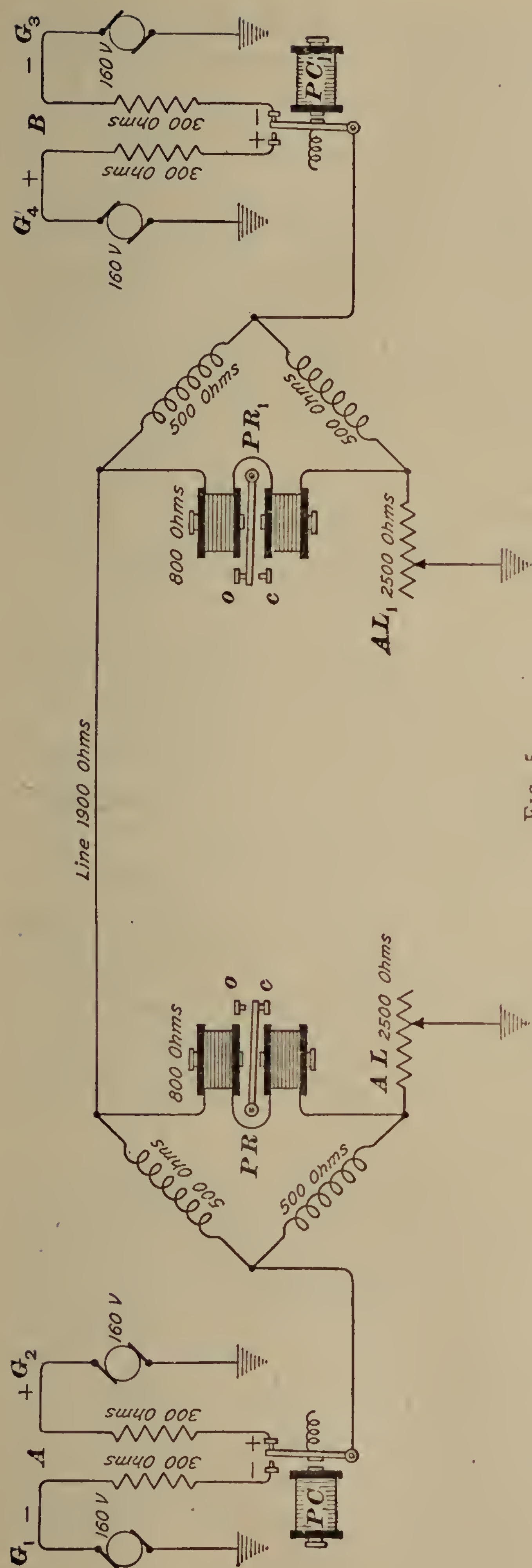

Fig. 5

In Fig. 5 it is to be understood that the pole changers *PC* and PC_1 are operated by sending keys and local batteries, also that the polar relays *PR* and PR_1 actuate reading sounders which are connected to them by way of local batteries and the closed-contact points *c* of the relays. The reading-sounder circuit is closed when the armature of the relay is in contact with the point *c* and open when the armature rests against point *o*.

38. Operation.—The marking elements of the Morse letters are transmitted to the line and to the distant polar relay by successive contacts between the armature lever of the pole changer and the marking contact of the pole changer. These operations follow regularly the closing and opening of the Morse key or semi-automatic transmitter used by the operators to actuate the pole changers.

In the following, it is assumed that the generators at each terminal station are connected to the marking and spacing contacts of the pole changer as indicated in Fig. 5. In transmitting the letter a (dot-space-dash), the dot is sent out as a negative impulse, the space as a positive impulse, the dash as a negative impulse, and the letter terminated by a positive impulse. The letter s (dot-space-dot-space-dot) is formed by battery applications as follows: negative-positive-negative-positive-negative-positive. The letter m (dash-space-dash) is formed by negative-positive-negative-positive applications. Considering only the succession of polarities, the letter a and the letter m are formed by the same series of impulses: negative-positive-negative-positive. In the receiving relay, the difference between an a and an m is indicated by the shorter duration of contact of the dot as compared with the dash.

39. Current Conditions in the Bridge Circuits. The values of the currents in the various branches of the bridge duplex circuit may be calculated as follows: The simplest method of solving the problem is to consider each end separately, and to assume that one generator at the home station is active and that both of the generators at the distant station are cut out of circuit, but that one generator resistance coil is grounded. The currents in the circuits for each case are calculated and are then combined to give the values of the currents when one generator at each of the two stations is active. It is impractical to present the derivation of some of the formulas employed in this demonstration.

40. In Fig. 6 (*a*), (*b*), (*c*), and (*d*) is shown the current in the various branches of a polar-bridge duplex circuit for the four possible positions of the two pole changers, one at each end. The keys that would be used to control the pole changers are not shown. The arrows represent the direction of the currents under the different conditions. The numbers on the arrows represent the current, in milliamperes, in the various parts of the circuit; numbers on devices represent their resistance, in ohms, and numbers opposite generators represent the voltage between their terminals.

The two positions of the key at Scranton, as shown in (*a*) and (*b*), give a current of the same strength and direction through the polar relay at Scranton, but reverse the direction of the current through the polar relay at Buffalo.

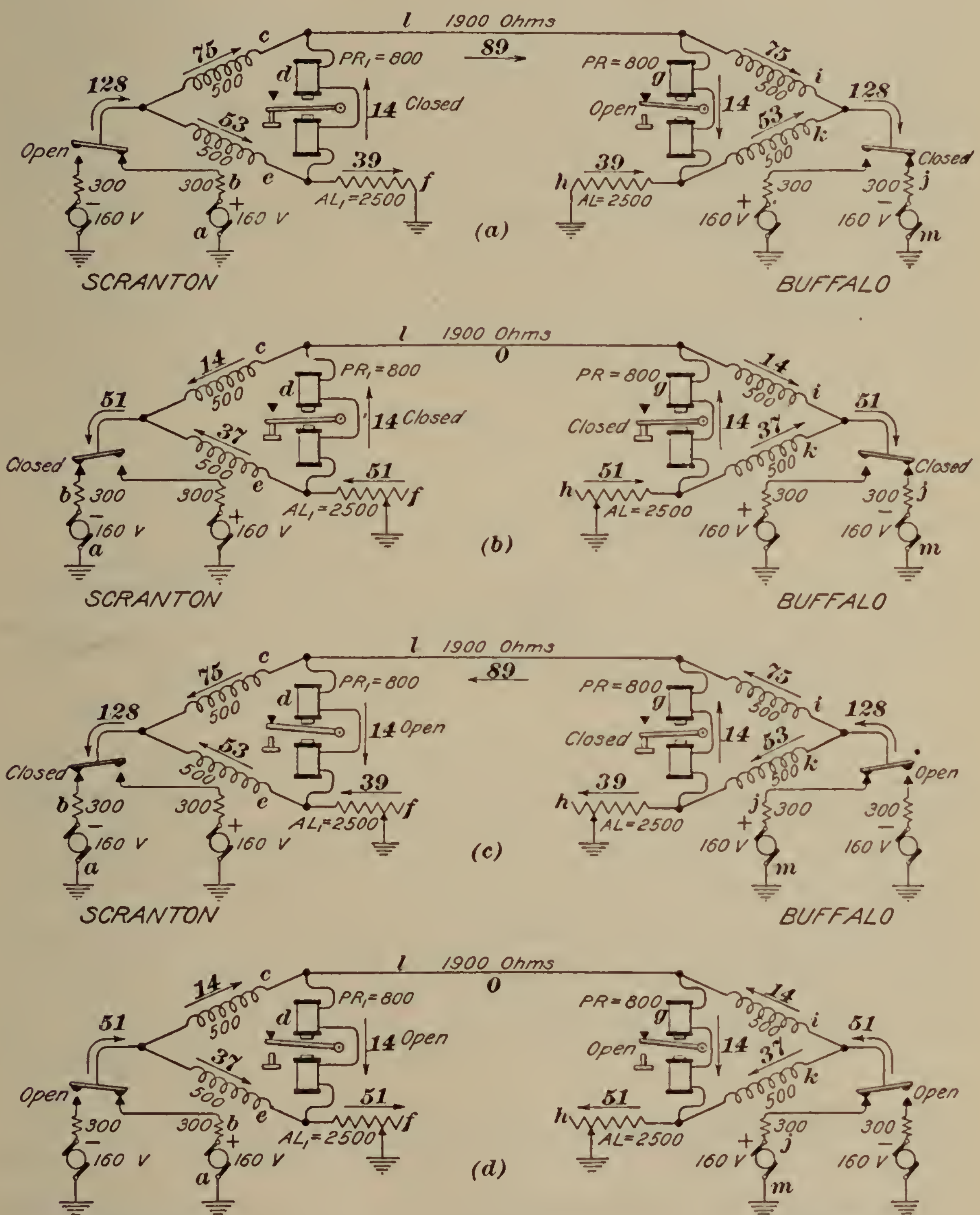

FIG. 6

41. The simplest calculations relate to the conditions indicated in Fig. 6 (*b*) and (*d*). There is no current in the line wire because opposing polarities of the active generators at the Scranton and Buffalo stations are connected to the line.

Under these conditions, the currents in the branches at a station depend upon the voltage applied at that station by the local generator.

Fig. 7 indicates the connections at the Scranton station with reference to the conditions shown in Fig. 6 (*d*). The voltage of generator *a*, Fig. 7, is 160. The current from the positive terminal of the generator passes through a series path *b* of 300 ohms; through two paths in parallel, one path $c+d=500+800=1{,}300$ ohms and the other path *e* of 500 ohms; and through a series path *f* of 2,500 ohms. The joint resistance of the two parallel paths is $\frac{(c+d)e}{(c+d)+e}=\frac{1{,}300\times 500}{1{,}800}=361$ ohms. The total resistance between the armature terminals is *b*

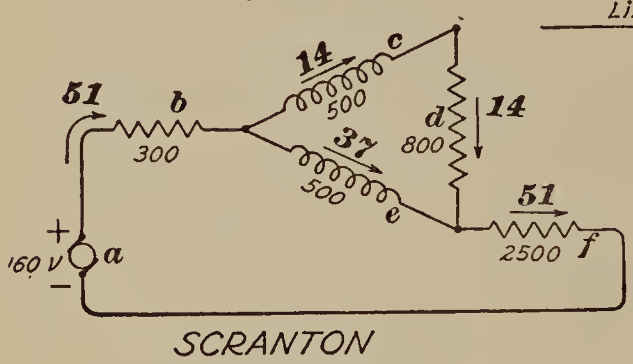

Fig. 7

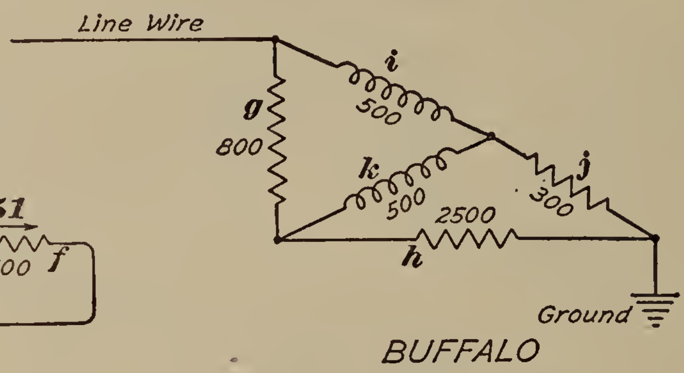

Fig. 8

plus joint resistance of $(c+d)$ and *e* plus $f=300+361+2{,}500=3{,}161$ ohms. The current in *b* and in *f* is $\frac{160}{3{,}161}=.051$ ampere $=51$ milliamperes, approximately. The voltage between the junction point of *c* and *e* and the junction point of *d* and *e* is $.051\times 361=18.4$ volts. The current in path *e* is $\frac{18.4}{500}=.037$ ampere $=37$ milliamperes and through path $(c+d)$ is $\frac{18.4}{1{,}300}=.014$ ampere $=14$ milliamperes. The values of the currents just calculated and their directions are indicated in Figs. 6 (*d*) and 7. In the Buffalo station, Fig. 6 (*d*), the values of the currents and their directions are the same as in the Scranton station because the positive terminals of the active generators at each station are connected to the line.

In Fig. 6 (*b*), the values of the currents are the same as in Fig. 6 (*d*), but the directions of the currents in the various paths are opposite in the two cases because the negative terminals of the two active generators, Fig. 6 (*b*), are now applied to the line.

42. Consider the case indicated in Fig. 6 (*a*). At the Buffalo station first determine the joint resistance of the terminal apparatus from the junction point of the line wire with the bridge to the ground. The generator at Buffalo, shown in Fig. 6 (*a*) as active, is assumed to be cut out, but its 300-ohm series resistance is grounded. Fig. 8 indicates the connections of the bridge arms for determining the joint resistance. Figs. 6 (*a*) and 8 should be compared.

The formula for determining the joint resistance of this net work of conductors, Fig. 8, is

$$R=\frac{k(i+j)\ (g+h)+ig\ (j+h)+jh\ (i+g)}{k\ (i+j+g+h)+(i+g)\ (j+h)}$$

Substituting the resistance values,

$$R=\frac{500(500+300)(800+2{,}500)+500\times 800(300+2{,}500)+300\times 2{,}500(500+800)}{500(500+300+800+2{,}500)+(500+800)(300+2{,}500)}$$
$$=600\text{ ohms}$$

The resistance of the artificial line of a duplex system, when properly balanced, is equal to the resistance of the main-line wire plus the joint resistance of the terminal apparatus at the distant station. In Fig. 6, the line wire has a resistance of 1,900 ohms and the joint resistance of the terminal apparatus at either the Buffalo or Scranton stations is 600 ohms, as just calculated. The artificial line must have a resistance of 1,900+600=2,500 ohms, as indicated in Fig. 6.

43. If an electromotive force is applied at the Scranton station, and the terminal apparatus at Buffalo is arranged as shown in Figs. 8 and 9, the current will be divided at the junction point of the two 500-ohm bridge arms at the Scranton station. One-half of the generator current will pass through the upper 500-ohm bridge coil, the 1,900-ohm line wire, and the 600-ohm terminal apparatus to ground. The resistance of this path is 3,000 ohms. The other half of the current will pass through the lower 500-ohm bridge coil and the 2,500-ohm artificial-line resistance to ground. The resistance of this path is also 3,000 ohms. Under these balanced bridge conditions, there will be no current in the 800-ohm polar relay at the Scranton office.

The circuit arrangement is indicated in Fig. 9. The joint resistance of the two parallel paths from the junction point of the bridge at Scranton is

$$R_1=\frac{(500+1{,}900+600)\quad(500+2{,}500)}{(500+1{,}900+600)+(500+2{,}500)}=\frac{3{,}000\times 3{,}000}{6{,}000}=1{,}500 \text{ ohms}$$

The total resistance of the circuit from the positive generator terminal through the current paths to the negative terminal is the sum of the series resistance 300 ohms and the joint

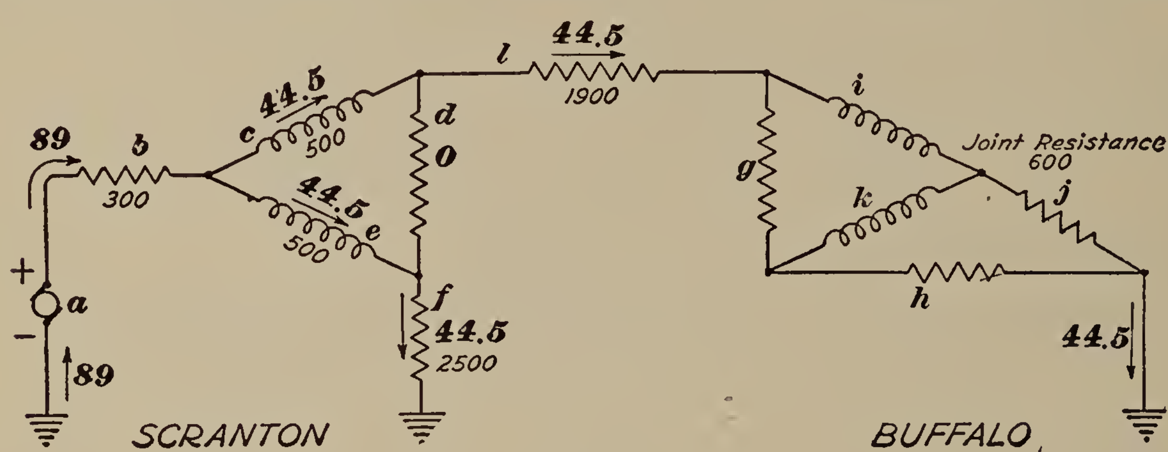

Fig. 9

resistance 1,500 or 1,800 ohms. The current in the generator a is $\frac{160}{1{,}800}=.089$ ampere $=89$ milliamperes. The current in each of the two parallel paths is $\frac{89}{2}=44.5$ milliamperes. The current in b, Fig. 9, is 89 milliamperes; in c, 44.5; in l, 44.5; in e, 44.5; in f, 44.5; and in d, 0.

44. Now consider the minus terminal of the generator m at Buffalo to be connected to the line, Figs. 6 (a) and 10, the generator a at Scranton cut out, and the 300-ohm resistance b connected to the ground. As the positive terminal of the generator is connected to the ground at Buffalo, there will be a current of 44.5 milliamperes in l in the same direction as the current in l in Fig. 9. The total current in the line wire l

is equal to 44.5+44.5=89 milliamperes when the positive terminal of the generator *a* at Scranton and the minus terminal of the generator *m* at Buffalo, Fig. 6 (*a*), are connected to the line

The current through the polar relay *d* of the bridge may be determined by the following formula in which the total line current I_l is taken as .089 ampere and the terminal voltage E of one generator is taken as 160.

$$I_d = \frac{cI_l(2b+f+c) - cE}{(f+b)(2c+d)+c\ (c+d)}$$

Substituting values,

$$I_d = \frac{(500 \times .089)\ [(2 \times 300) + 2{,}500 + 500] - (500 \times 160)}{(2{,}500 + 300)\ [(2 \times 500) + 800] + 500\ (500 + 800)} = .014 \text{ ampere}$$
$$= 14 \text{ milliamperes.}$$

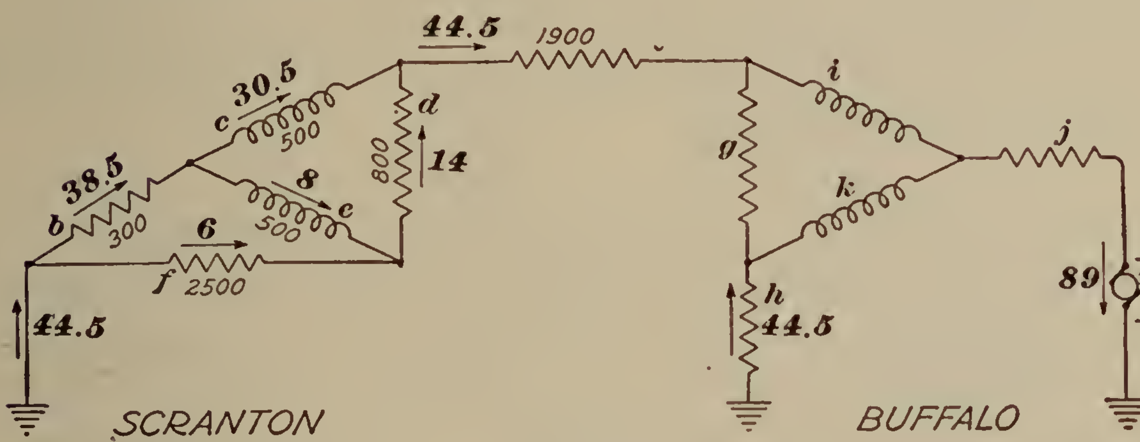

FIG. 10

45. Now determine the currents in the bridge arms under the conditions indicated in Fig. 10. A current of 44.5 milliamperes, or .0445 ampere, which is a part of the current established by the generator *m* at Buffalo, passes from the ground at Scranton to the junction point of *b* and *f*. The drop in voltage between the junction point of *b* and *f* and the junction point of *c* and *d* is .0445×600=27 volts. The current through *d* is .014 ampere as just determined, then, since as much current passes toward a point as passes away from it, the current through *c* must be .0445−.014=.0305 ampere, or 30.5 milliamperes. The drop in voltage along *d* is .014×800 =11.2 volts; the drop along *c* is .0305×500=15.25 volts. The voltage of 27 applied to the network, Fig. 10, acts to force current from the ground junction point to the line junction point. There is a drop of voltage of 27−15.25=11.75 along

b, and a drop of $27-11.2=15.8$ along f. The voltage at the junction point b, e, c, that tends to force current through e toward the right, is 27 volts minus the drop in volts in b, or $27-11.75=15.25$, and the voltage opposing this action at the junction point f, e, d is 27 volts minus the drop in volts in f, or $27-15.8=11.2$. The effective voltage acting toward the right is $15.25-11.2=4.05$ and the current in e is $\frac{4.05}{500}=.008$ ampere, or 8 milliamperes.

The current through b toward the junction point b, e, c is equal to the sum of the currents passing from this junction point, or $.0305+.008=.0385$ ampere, or 38.5 milliamperes. Since .014 ampere passes away from the junction point f, e, d and a current of .008 ampere passes toward the point, the current in f must be toward the point and of a value of .006 ampere, or 6 milliamperes.

46. In Figs. 9 and 10, the values of the currents, expressed in milliamperes, and their directions are indicated for the two cases under consideration. The total sum of the currents in the branches, when the two generators act in series, as indicated in Fig. 6 (a), are equal to the sum of the currents shown in Figs. 9 and 10. When the arrows in the two figures agree in direction, the values are added and the resulting current has the same direction as either of the component parts. When the arrows of the component parts are in opposite directions, the values are subtracted and the total current takes the same direction as that of the larger component current. The only example of the difference of currents is that of 44.5 milliamperes for f, Fig. 9, passing downwards and 6 milliamperes for f, Fig. 10, passing upwards. The total current for f, Fig. 6 (a), is $44.5-6=39$ milliamperes, approximately, passing downwards.

Fig. 6 (c) shows a condition in which the negative terminal of the generator a at Scranton and the positive terminal of the generator m at Buffalo are connected to the line. The values of the currents are the same as in Fig. 6 (a), but their directions are reversed.

47. Terminal Equipment Connections.—Fig. 11 shows each unit of the main-line terminal equipment of a Western Union bridge duplex set connected in its proper position. The generators are shown at *a*; the resistance lamps in series with the generator at *b*; the pole changer at *c* with its marking contact at *d* and its spacing contact at *e*; the spark condenser at *f*; the retardation coil at *g*; the balancing meter at *h*; the polar relay at *i*; the adjustable main-line

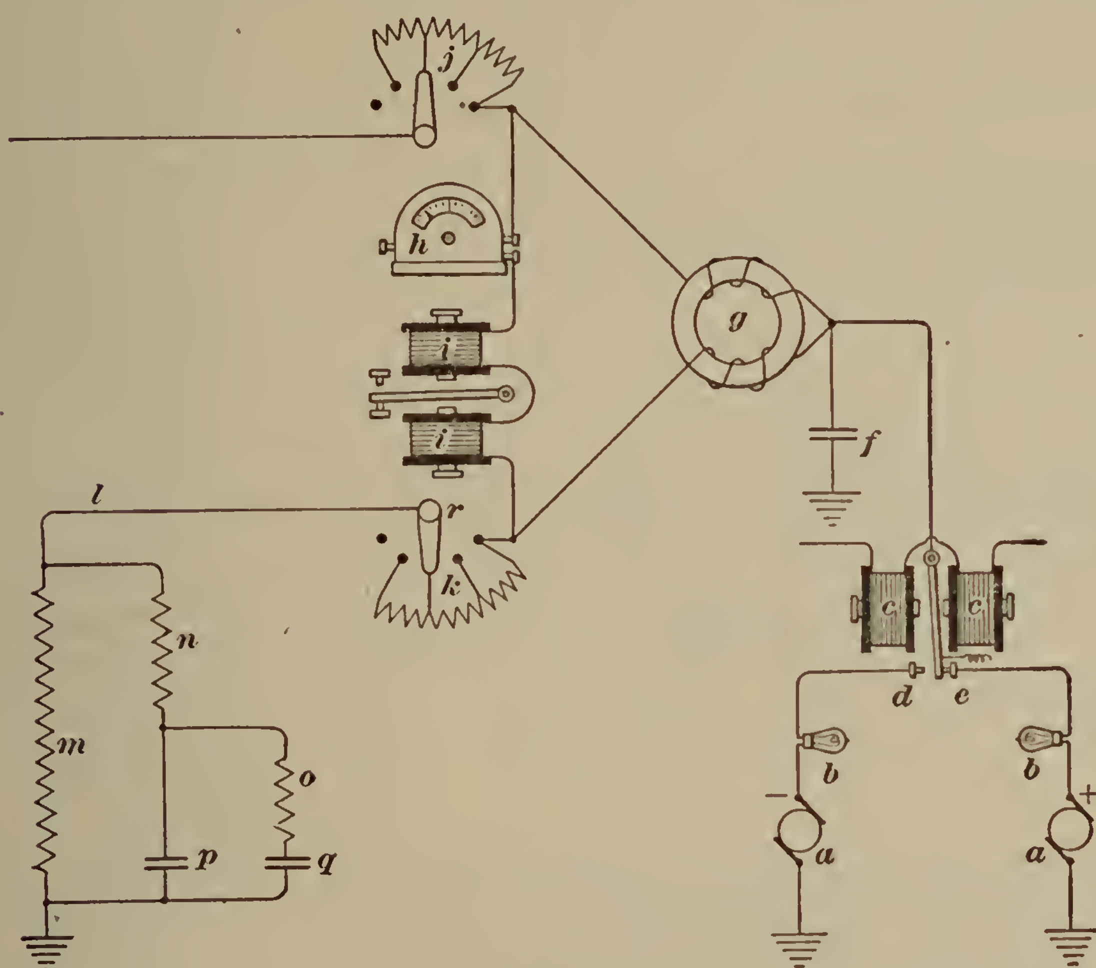

FIG. 11

resistance at *j*; the adjustable compensating artificial-line resistance at *k*; the artificial line at *l*; three resistance sets of the artificial line at *m*, *n*, and *o*; and the first and second condensers of the artificial line at *p* and *q*. The contact arm *r* of the rheostat *k* is connected to the relay binding post of the radial-arm rheostat, Fig. 15, which contains the three resistance sets of the artificial line.

48. Polar Relay.—The type of polar relay shown in Fig. 12 is used by the Western Union Telegraph Company and by many railroad telegraph departments operated in connection with Western Union lines.

Two **J**-shaped permanent magnets have their south poles adjacent to each other, being connected mechanically by a bridge of soft iron. The armature of the relay is pivoted in the center of the soft-iron bridge piece, but a small air gap exists between the soft-iron armature and the bridge. Magnetic induction across the air gap gives to the pivoted end of the armature a north polarity, from which it follows that the free end of the armature is of a south polarity. When there is no current in the electromagnets of the relay, the armature is subject to equal attraction from the two north ends of the permanent magnets, and if the armature is moved by hand to the right or left, it will remain in contact with either post, provided, that when the armature is midway between the contact posts it is also midway between the pole faces of the magnets. This is what is known as a *magnetic balance* of the relay. When the marking and spacing contacts of the relay between which the armature plays are so adjusted that the armature may approach closer to one pole face than to the opposite pole face, the relay is said to be *biased*. The bias may be in favor of the marking current or the spacing current.

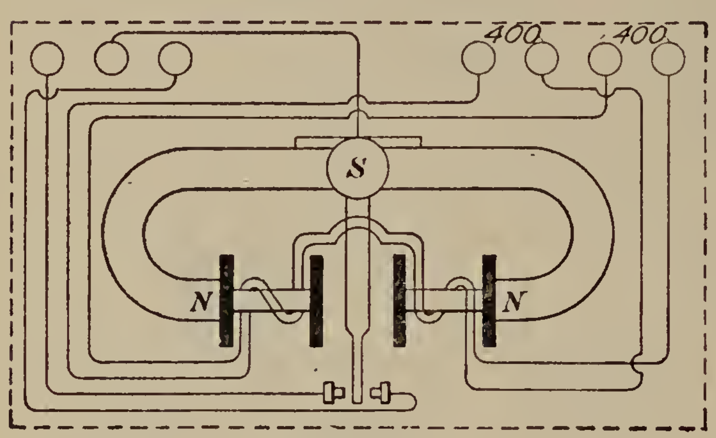

Fig. 12

The wire windings which form the electromagnets mounted on the ends of the permanent magnets terminate at binding posts. In the bridge duplex system, the two 400-ohm windings should be connected in series which requires that the main-line connection be made to the first post at the right-hand side, the artificial-line connection to the fourth post, and that a short wire be used to connect the second and third posts together, making the resistance of the two windings in series equal to 800 ohms.

The fact that each winding passes around the cores on both sides of the armature signifies that the current due to the terminal battery tends to demagnetize one of the pole pieces and to increase the magnetism in the opposite pole piece. Therefore, instead of the armature being equally attracted by both poles, as when a magnetic balance obtains, the armature is but feebly attracted by one pole and strongly attracted by the other, which causes the armature to move rapidly to the right or the left, depending upon the direction of current through the windings. The binding posts for the armature and its contacts are shown at the left.

49. Pole Changer.—The purpose of the pole changer is to control the movements of the armature between the marking and spacing contacts. The pole changer is operated by means of a key circuit in series with a local battery. Fig. 13 shows the wiring connections of the Western Union type pole changer. Two electromagnets, one on each side of the armature, have their windings connected in series. The iron core of the magnet on the right is of laminated construction and the core of the magnet on the left is of solid iron surrounded by a copper sleeve. When the circuit of the coils is closed, the increasing current establishes by induction a current in the cores and this current is in such a direction as to retard the building up of the magnetic flux of the electromagnet.

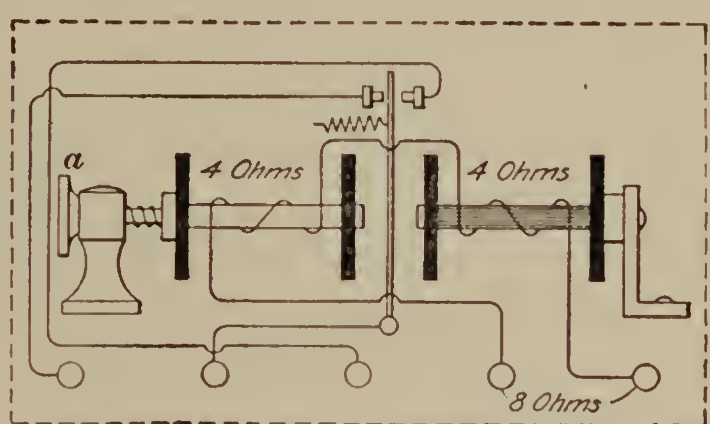

Fig. 13

With the laminated core, the current induced in the core has a comparatively low value because of the high contact resistance between the individual rods making up the core. The retarding effect is, therefore, small and the magnetic flux will increase quickly when the circuit of the electromagnets is closed and for similar reasons fall quickly when the circuit is opened.

In the solid core on the left, the induced current is much larger, because of the low resistance to the passage of the induced current offered by the solid core and the copper sleeve. The retarding effect is much greater and the magnetic flux does not increase to its maximum value or decrease to its minimum value as quickly as in the case of the laminated core. The left electromagnet is, therefore, slow acting as compared to the one on the right. A screw at *a*, Fig. 13, allows the position of the electromagnet on the left to be adjusted.

50. In the operation of any duplex telegraph system, it is of the utmost importance that the transit time of the armature between the contact points of the pole changer be kept to as low a figure as is possible. Attached to the armature is a light spring which serves to hold the armature against the back contact when the key circuit controlling the pole changer is open. When the sending key is closed, as in the act of transmitting a Morse character, current actuates both electromagnets of the pole changer, and, due to its quick acting core, the magnet on the right immediately acquires sufficient strength to attract the armature to the front, or marking, contact. The opposite magnet, although energized from the same source of current acquires its magnetic strength more gradually. When the magnetic flux of each electromagnet has been built up to its maximum value, the armature will still remain against the front contact and keep in that position as long as the key is held closed, because the armature is closer to the pole face of the right-hand magnet. At the instant the key is opened, thus opening the circuit through the windings of the electromagnets, the magnetism in the laminated core to the right disappears quickly, while the magnetism in the copper-jacketed solid core on the left disappears more slowly, the result being that the armature is instantly moved from the marking contact to the back, or spacing, contact.

51. Line-Resistance Box.—Fig. 14 shows the two sets of adjustable resistances indicated at *j* and *k*, Fig. 11. One resistance set is in series with the main line and the other set in series with the artificial line. These two resistance sets are contained in one box as shown in Fig. 14. The amount of resistance introduced in each circuit may be varied in steps from 0 to a total of 1,250 ohms. The contact arms are mechanically joined so that for a movement of the common handle, the same resistance will be added to or taken from the main-line and the artificial-line circuits. When the resistance is altered, it is necessary to advise the distant terminal office so that like changes may be made at that end of the line and so that conditions at the ends of the circuit can be equalized.

52. Purpose of the Line-Resistance Box.—The insertion of added resistance in the line immediately in advance of the relay circuit is of advantage in compensating for sudden changes in the insulation resistance of the line. With from 250 to 1,250 ohms, perfectly insulated from the earth, forming a part of the line circuit, the insulation resistance per mile of the entire main circuit is considerably higher, as a result of which greater variations may occur in the exposed section of line without seriously disturbing the balance between the main and the artificial line.

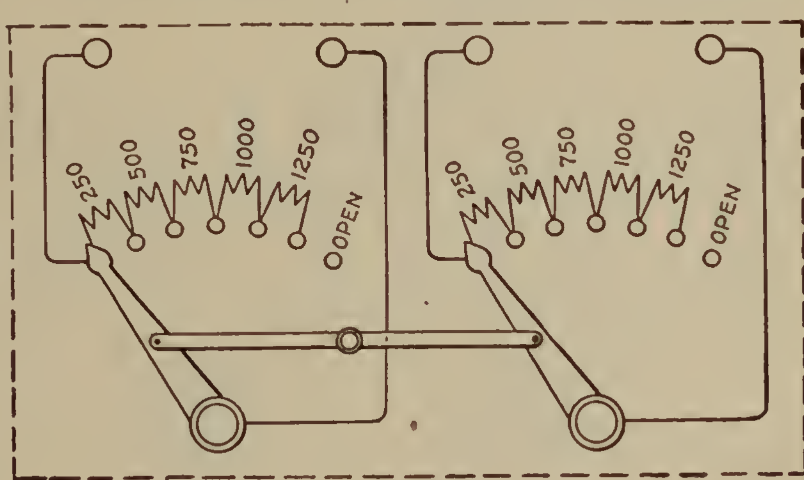

FIG. 14

The line-resistance box may also be used to increase the equivalent electrical length of comparatively short line wires which it may be desired to duplex. A line having a resistance of but a few hundred ohms cannot be duplexed satisfactorily using terminal apparatus supplied from potentials capable of being applied to long lines. Relatively high potentials connected to low-resistance lines produce currents which heat the relay windings excessively. Such lines may be operated by inserting added resistance in series with the line and the artificial line. The resistance box, Fig. 14, is used for this purpose.

53. Radial-Arm Rheostat.—The radial-arm rheostat, Fig. 15, contains the groups of resistances indicated in Fig. 11 at *m*, *n*, and *o*. Manipulation of the arms *a*, *b*, and *c*, Fig. 15,

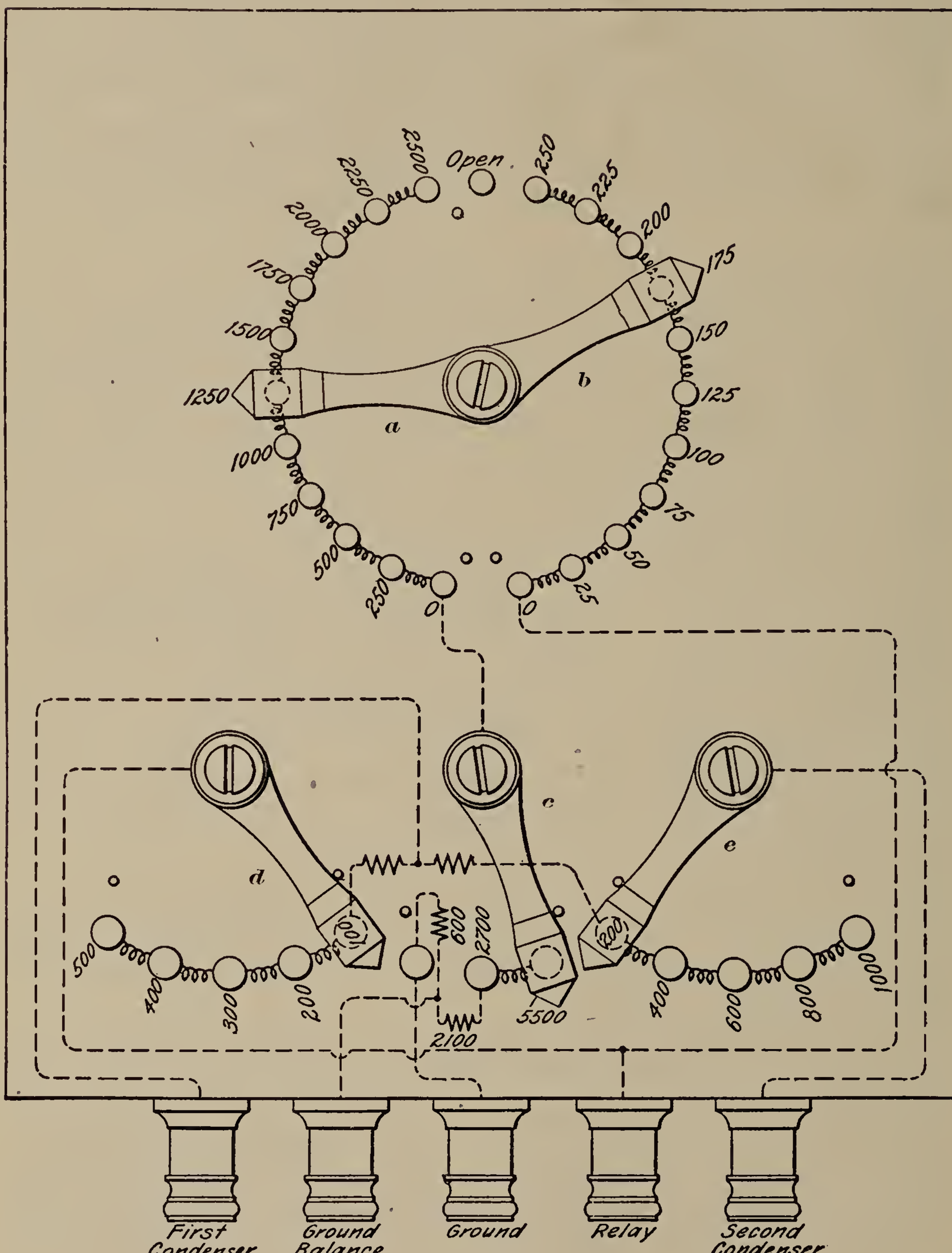

Fig. 15

of the large rheostat regulates the resistance in circuit between the relay terminal and the ground terminal. The arms *d* and *e* serve to regulate the resistance in series with the condensers *p* and *q*, Fig. 11, of the artificial lines. The relay terminal, Fig. 15, is connected to the point *r* in Fig. 11. In some rheostats there are four contact points over which arm *c*, Fig. 15, moves; the numbers relating to the resistance values for the second, third, and fourth contact points are then 2,750, 5,500, and 8,250.

54. Combination Condenser.—The combination condenser, Fig. 16, includes three groups of condensers, two being adjustable as to capacity and the third non-adjustable. Each of the adjustable groups has a total capacity of $3\frac{7}{8}$ microfarads, made up of units of $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 microfarads. One group is represented by condenser *p*, and the other group by condenser *q*, Fig. 11. In Fig. 16, the first and second con-

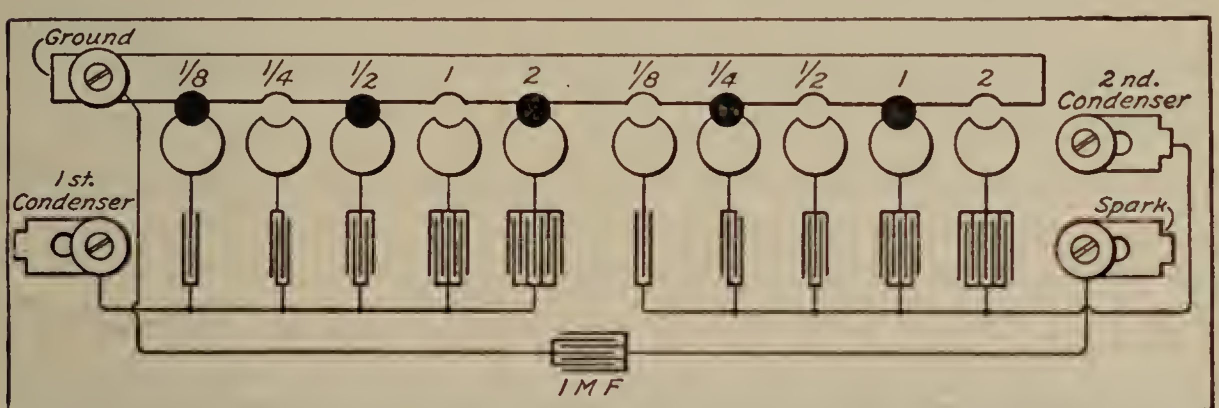

FIG. 16

denser terminals are connected to the corresponding terminals of the radial-arm rheostat, Fig. 15. The non-adjustable, 1-microfarad condenser, Fig. 16, is connected as shown at *f*, Fig. 11, and is known as a spark condenser.

55. The 5-U Retardation Coil.—The 5-U retardation coil with its connections to the bridge circuit is indicated at *g*, Fig. 11. The core is built up of small iron wires. The two coils are differentially wound and each has a resistance of 500 ohms.

When electricity starts to flow from the line wire into the line side of the retardation coil, an electromotive force is induced in the other winding of the retardation coil by mutual induction, or transformer action. Also the impedance of the winding of the line side is somewhat increased. The result of these actions is to unbalance the electrical conditions of the retardation coil and to establish a considerable difference of potential between the points to which the polar relay is connected. For any change in the positions of the pole changers, the effects of mutual induction and self induction of the retardation coils as compared with the effects of a non-inductive resistance are to accelerate the rate at which the currents change through the polar relays. The armatures of the polar relays thus move rapidly from one contact post to the other. After a short interval, the currents in the two windings of the retardation coil reach their normal values for the positions of the pole changers and the resistance conditions of the bridge.

To insure quick response of the relay armature with non-inductive bridge arms would require the bridge arms to be of high resistance so as to establish a considerable difference of potential between the relay terminals. A satisfactory resistance for non-inductive windings in each arm is about 3,000 ohms. By using inductive windings, it is possible to reduce the resistance to 500 ohms in each arm.

Outgoing current from the home pole changer divides into two currents which pass through the differentially connected retardation coils. The magnetic action of one coil is partly neutralized by the opposing magnetic action of the other coil. There will be, however, some lines of force established in the cores on which the coils are wound and, therefore, the coils possess some inductance. The retardation has the effect of graduating the increase in value of the outgoing current. Under these conditions, telephone lines on the same pole line as the telegraph wires are subjected to minimum inductive effects from the duplex signals.

BALANCING THE WESTERN UNION BRIDGE DUPLEX

56. Balancing Meter.—Practically all of the later types of duplex sets have balancing meters connected permanently as a part of the terminal apparatus. In the Western Union bridge duplex, the balancing meter is connected in series with the relay as shown at *h*, Fig. 11. This balancing meter has a resistance of 1 ohm and only about one-fifth of the line current passes through it. The scale will register up to a current of 50 milliamperes on each side of the zero position at the center. When the armature of the polar relay is in its marking position, the pointer of the milliammeter is on the marking side of the scale. When the armature is in its spacing position, the pointer of the milliammeter is on the spacing side of the scale.

57. Resistance Balance.—First request the distant station operator to close the sending key. This action sends out negative current from that station causing the pointer of the milliammeter at the home station to deflect to the marking side of zero. Note the degrees of deflection of the pointer after it has come to rest, first with the home sending key open, and again with the key closed. With the home key in the closed position, adjust the resistance of the artificial line until the meter pointer reaches a point midway between the two readings previously noted.

58. Static Balance.—A static unbalance between the main and the artificial lines is indicated when the meter pointer kicks from its steady position at the instant the home key is depressed and in the reverse direction at the instant the home key is opened, the pointer returning to normal position in each case when the home key is at rest. The distant key is assumed to be closed.

If, when the home key is closed, the pointer kicks in a spacing direction, that is, from its normal marking deflection toward zero and then instantly returning to normal position, this signifies that the capacity of the condensers in the artificial line is less than that necessary to compensate for the capacity of the line wire, and that the capacity should be increased.

If, when the key is closed, the pointer kicks farther in the marking direction, the capacity of the artificial-line condensers should be decreased. When the capacity of the artificial line is the same as that of the real line, there will be no movement of the meter pointer, whether the key is closed or opened, provided also that the resistance balance has been established.

59. Effect of Retardation Resistance During Balance Test.—When the timing, or retarding resistances, in series with the condensers are not adjusted to the proper values, the time taken to charge and discharge the artificial line will not coincide with that taken to charge and discharge the line wire. If the difference is pronounced, the meter pointer gives a double kick each time the sending key is opened and closed. The action of the pointer under these conditions is readily distinguished from the forward and backward kick due to ordinary static unbalance. While rapidly dotting with the key, the resistances of the retarding coils should be adjusted until the pointer registers minimum disturbance as a result of applying positive and negative current alternately to the line.

IMPROVED POLAR BRIDGE DUPLEX

60. Connections.—Fig. 17 shows the connections of a modified polar bridge duplex system used in the leased-wire service of the American Telephone and Telegraph Company. The principle of operation of this system is similar to that of the system described in Art. **5**, but certain changes have been made in the apparatus so as to avoid inductive disturbances in telephone circuits on the same pole line or in the same cable. The explanation of the operation of the line relays in the Western Union bridge duplex system, Art. **38**, also holds true for the action of the line relays here considered.

In Fig. 17 a sending loop and a receiving loop are shown. These loops extend to a subscriber's station or to a branch office, and, by providing sending and receiving apparatus for the loops, the operator at that point may send and receive over a duplexed line although the duplex apparatus is situated at the main office of the telegraph company.

61. Artificial Line.—The artificial line has a two-lever, four-point switch *a* which is thrown to the left when the line wire in use is one wire of a two-wire telephone circuit, and to the right when the line circuit consists of the two wires of a telephone circuit which wires constitute a joint path for the telegraph current.

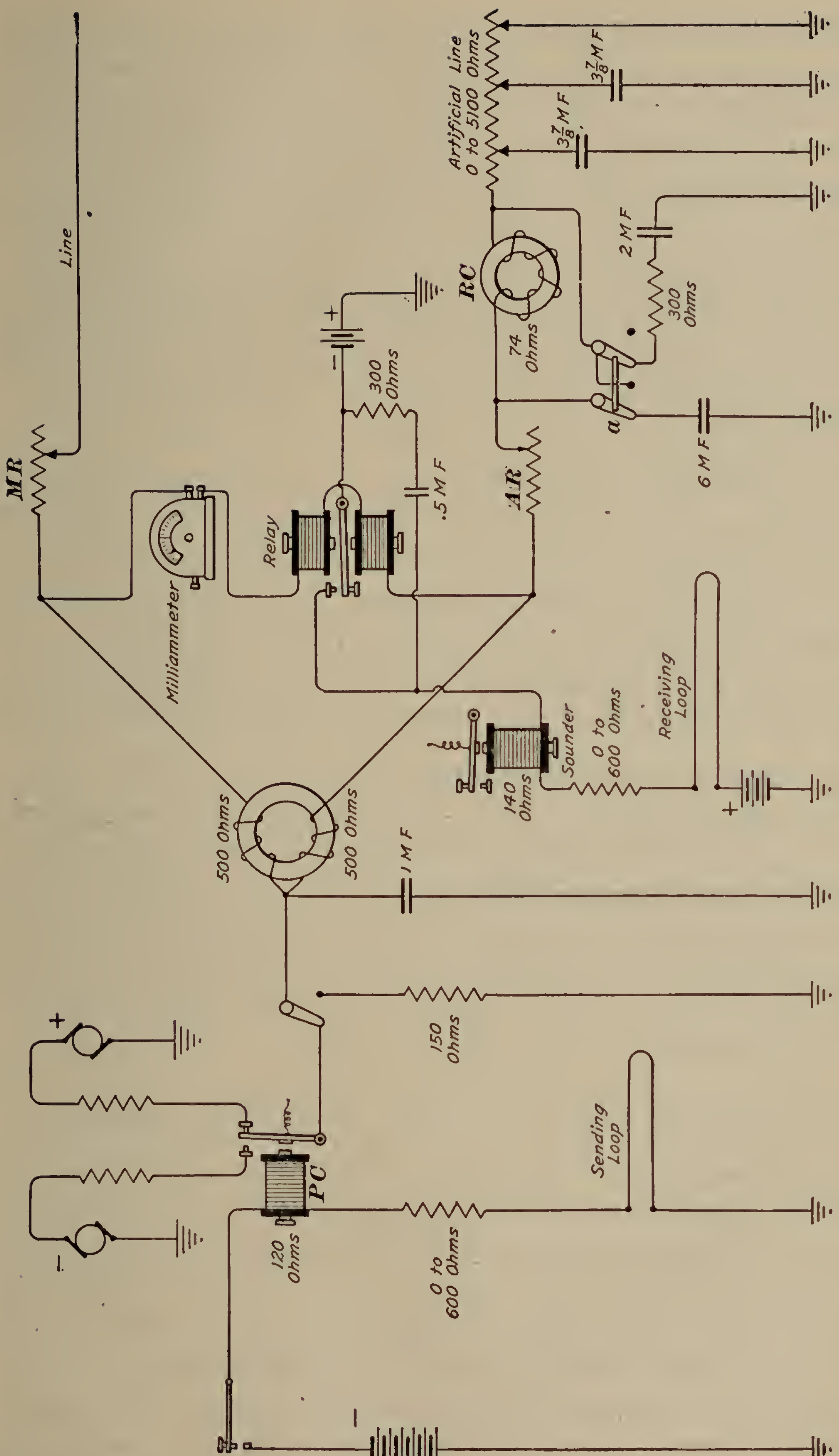
Line
MR
Milliammeter
Relay
300 Ohms
.5 M F
AR
RC
74 Ohms
Artificial Line 0 to 5100 Ohms
3 7/8 M F
3 7/8 M F
2 M F
300 Ohms
a
6 M F
Sounder
140 Ohms
0 to 600 Ohms
Receiving Loop
500 Ohms
500 Ohms
1 M F
150 Ohms
Sending Loop
PC
120 Ohms
0 to 600 Ohms

Fig. 17

With the switch *a* thrown to the right, the modified bridge duplex may also be operated over a single wire not associated with telephone circuits. With the switch at its left-hand position as shown in Fig. 17, the adjustable resistance *AR*, which is in series with the retardation coil *RC* and the artificial-line resistance, has a discharge path to ground through a 6-microfarad condenser. Also a 2-microfarad condenser in series with a 300-ohm resistance forms a path to ground from the artificial line side of the retardation coil. When the switch is to the right, the two condenser paths are opened and the retardation coil is short-circuited.

62. Purpose of Retardation and Capacity Circuits. The purpose of the retardation coil and condensers, when the set is being operated over one wire of a two-wire telephone circuit, is to balance similar retardation and capacity circuits included in the telephone equipment at the same station and connected to the same line wire. The purpose of the adjustable resistances *MR* and *AR*, Fig. 17, was explained in Art. 52.

63. Spark Control at Relay Contacts.—The contact between the armature of the relay and the active contact point is shunted by a circuit that includes a $\frac{1}{2}$-microfarad condenser and a 300-ohm resistance. When the receiving loop is extended to a branch office through a considerable length of cabled conductor, the circuit possesses inductance and the shunt circuit around the contact tends to minimize the sparking at this point.

BALANCING THE A. T. AND T. BRIDGE DUPLEX

64. Resistance Balance.—With the duplex sets at both terminal stations arranged for double transmission, make the resistance of the artificial-line rheostat equal to the estimated resistance of the line wire plus 500 ohms, the latter amount approximating the resistance of the terminal circuits and apparatus at the distant station. If the resistance of the line is unknown, vary the resistance of the artificial line until the operation of slowly forming dashes with the sending key does not affect the pointer of the balancing meter. The distant key is assumed to be open. Should the pointer move farther away from zero on the spacing side when the home key is closed than when open, the artificial-line resistance should be increased. If, when the key is closed, the pointer moves toward zero from its former spacing position, the artificial line resistance should be decreased.

65. Capacity Balance.—The capacity of the line may be estimated as 1 microfarad for each 100 miles of pole-line wire, or for each ten miles of cabled conductor.

Vary the capacity of the condensers in the artificial line until the pointer of the meter does not kick in either direction when the home key is slowly opened and closed several times, the distant key being open. The artificial-line capacity should be about equally divided between the two condensers. When the key is closed, if the pointer is thrown farther away from zero in a spacing direction, the condenser capacity should be decreased. If the pointer is thrown toward zero from its normal spacing position, the condenser capacity should be increased.

66. Checking the Balance.—The main purpose of balancing the home set is to insure that incoming signals from the distant station will be properly recorded by the relay. In order to check the balance, after the resistance and capacity balances have been established as just explained, the distant station operator is asked to close his sending key. If now slowly operating the home key causes appreciable movement of the meter pointer, further adjustment of the resistance and capacity of the artificial line is necessary so that the pointer will finally indicate perfect balance. The position of the pointer when the distant key is open and when it is closed should be noted. Capacity and resistance adjustments may then be made which will cut in half the difference between the two values indicated

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BALANCING WITH AN UNDULATOR

67. The Undulator.—The undulator, Fig. 18, is a telegraph receiving instrument that records on a moving paper tape the signals corresponding to the positive and negative impulses sent out by the distant pole changer. Aside from its use as a recording instrument, the undulator is quite frequently employed to obtain very accurate balances on duplex and quadruplex lines. The instrument will record imperfections in signals which the ear might disregard when a sounder is used to determine the character of the passing signals.

68. Construction of the Undulator.—Fig. 18 (*a*) shows the electrical portion of the undulator. The two

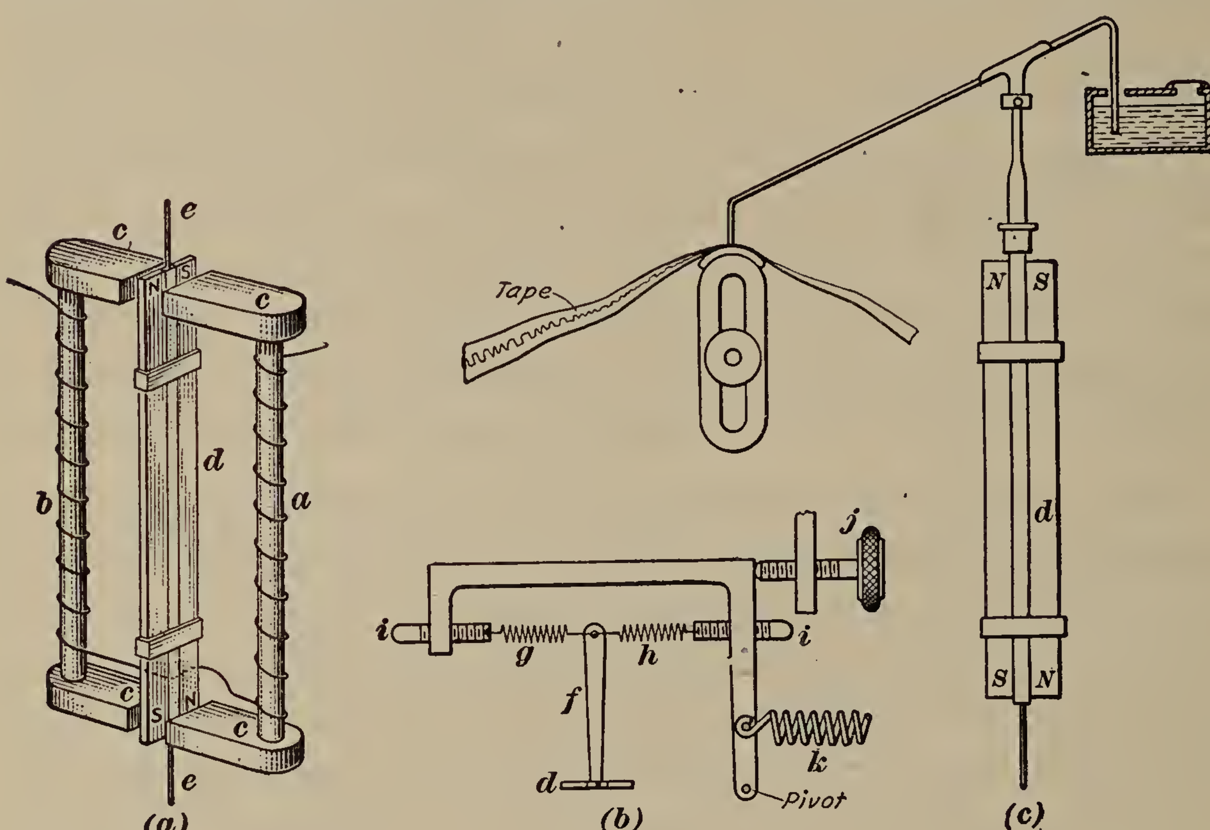


FIG. 18

electromagnets *a* and *b* are each wound to a resistance of 400 ohms. Pole pieces *c* project at right angles from the ends of the cores. The length of the air gaps between the pole pieces *c* and the armature *d* may be adjusted by moving the electromagnets. The armature *d* is made up of two permanent bar magnets mounted vertically on an aluminum support which is provided with steel pivots *e*. The permanent magnets are so mounted that their adjacent poles are of unlike polarity as indicated in view (*a*). When current passes through the electromagnets, the adjacent pole pieces are of unlike polarity. When the current is reversed, the polarity of each pole piece of the electromagnets is reversed. The armature will therefore turn in a clockwise direction for one direction of current through the coils and will turn in the other direction when the current is reversed.

An extension arm *f*, Fig. 18 (*b*), which projects at right angles from the armature *d* is held normally in a central position by two springs *g* and *h*. The tension of these springs can be adjusted by the threaded pins *i*. When the armature turns, its movement is opposed by one or the other of the springs. The position of the framework supporting the springs *g* and *h* is also adjustable by means of screw *j* and spring *k*.

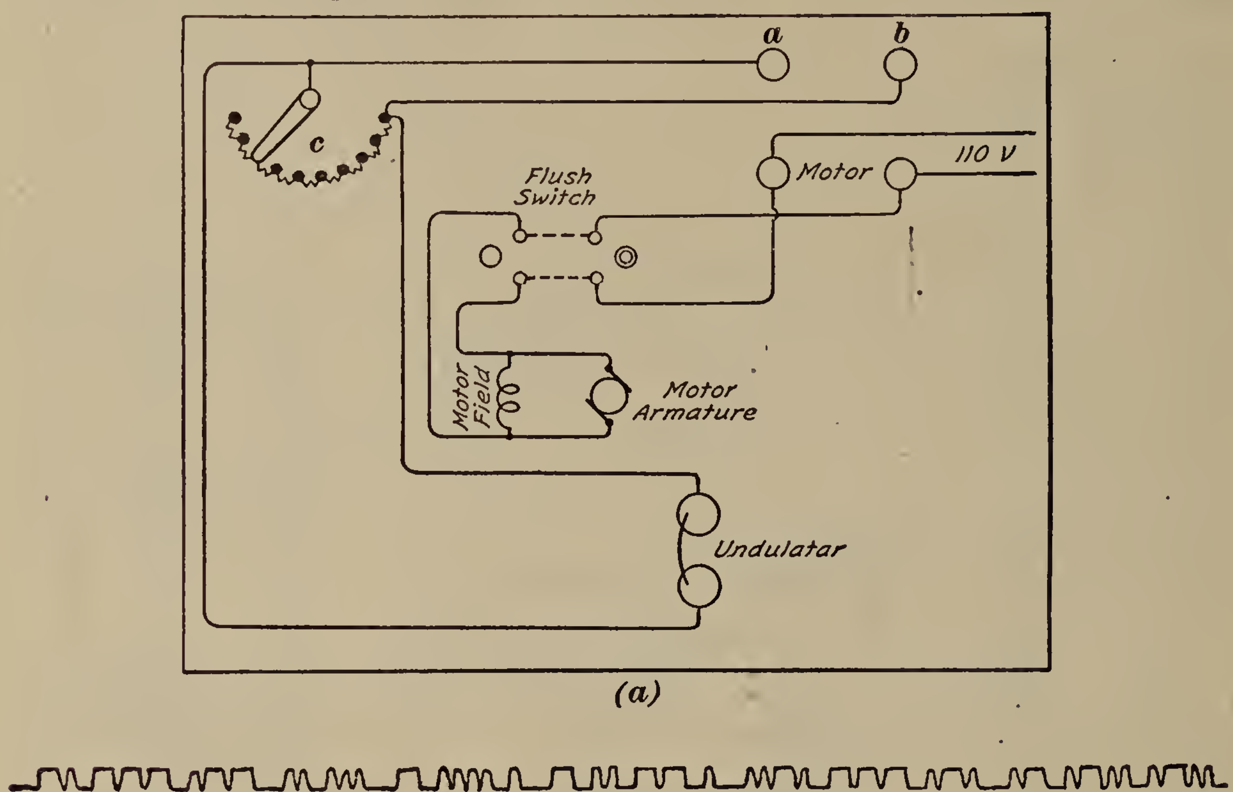
The inking device, Fig. 18 (*c*), consists of a fine silver or glass tube which is mounted on an extension of the armature *d* and turns with it. One end of the tube dips into an inkwell and the other end marks on the paper tape. When no current is in the electromagnets, the springs should be adjusted so that the pen rests on the middle of the tape. The movement of the paper is caused by a small motor acting through a friction drive. Current in the electromagnets causes marks to be made on one side or the other of the center line of the tape depending on the direction of the current.

69. Balance Tests.—Fig. 19 (*a*) shows the undulator, its shunt resistance, and the motor that moves the paper tape. When the undulator is used as a balance indicator on a duplex set, the terminal posts *a* and *b* leading to the coils of the undulator are connected across the main and the artificial lines of the duplex set.

An adjustable shunt resistance *c* is connected in parallel with the coils of the electromagnets so that the current in windings of the magnets of the undulator may be varied to suit conditions. At first too great a movement of the siphon is to be avoided. As the balance is improved, the shunt resistance may be increased until the best possible operating adjustment is made with the shunt circuit opened.

The operator at the distant station is asked to send out current reversals and the operator at the home station also transmits current reversals to the line. The resistance and capacity of the artificial line should be adjusted so as to produce on the paper tape regular and uniform indications on either side of the center line and with the home key either open or closed.

To balance for capacity, the condenser in the artificial line and the condenser retardation resistance should be adjusted until the undulations appearing on the tape are regular and uniform. Should the undulations appear as groups rising from minimum to maximum amplitude and



(b)

Fig. 19

returning to minimum again, the balance is imperfect and further adjustments should be made.

Fig. 19 (*b*) shows a section of a record, in international Morse, obtained by means of the undulator. The amplitude and shape of the signals can be regulated by three means: the shunt resistance; the length of the air gap between the armature and the pole piece; and the pressure of the pen on the paper tape. If square-topped signals are desired—and these are the most easily read—the shunt should be of as high resistance as possible, the air gaps fairly wide, and the pressure of the pen on the paper as light as possible.

The undulator may be used to obtain both the ohmic and static balances, but ordinarily the milliammeter method of balancing is first used, the undulator then being employed to obtain exact balance or to search for the cause of circuit defects which interfere with continuous accurate signaling.

SELF-BALANCING DUPLEX REPEATER STATION

70. Balancing With Spare Lines.—When a long telegraph line is duplexed, for example, between New York and Chicago, repeater stations are included in the system. For satisfactory operation, the apparatus at the terminal and repeater stations must be kept in proper adjustment and balance. The attendants at the repeater stations are required to listen occasionally to the signals passing through the station and to respond to requests from the terminal offices for readjustments. There are many occasions, especially on Sundays, holidays, and at night, when the services of an attendant could be dispensed with were it not for the duty of making local adjustments. Spare line wires and spare duplex sets may be employed so as to dispense with balancing at the repeater stations.

Fig. 20 shows a self-balancing duplex arrangement for duplex repeater stations devised by Stanley Rhoads. This arrangement obviates the necessity of maintaining continuous attention at repeater stations. Line wire *1* is duplexed between the terminal station *A* and the repeater station *B*, and line wire *2* is duplexed between the repeater station *B* and the terminal station *C*. The operation of the armature of relay *R* causes pole changer *PC* to transmit signals from wire *1* to wire *2*. The operation of the armature of relay R_1 causes pole changer PC_1 to transmit signals from wire *2* into wire *1*.

Instead of using the ordinary artificial line from point *a* of the bridge at the repeater station *B*, a spare line wire *3* together with a spare duplex set at the terminal station *A* is connected between point *a* at station *B* and the ground at station *A* and constitutes the artificial line *AL*. The resistance,

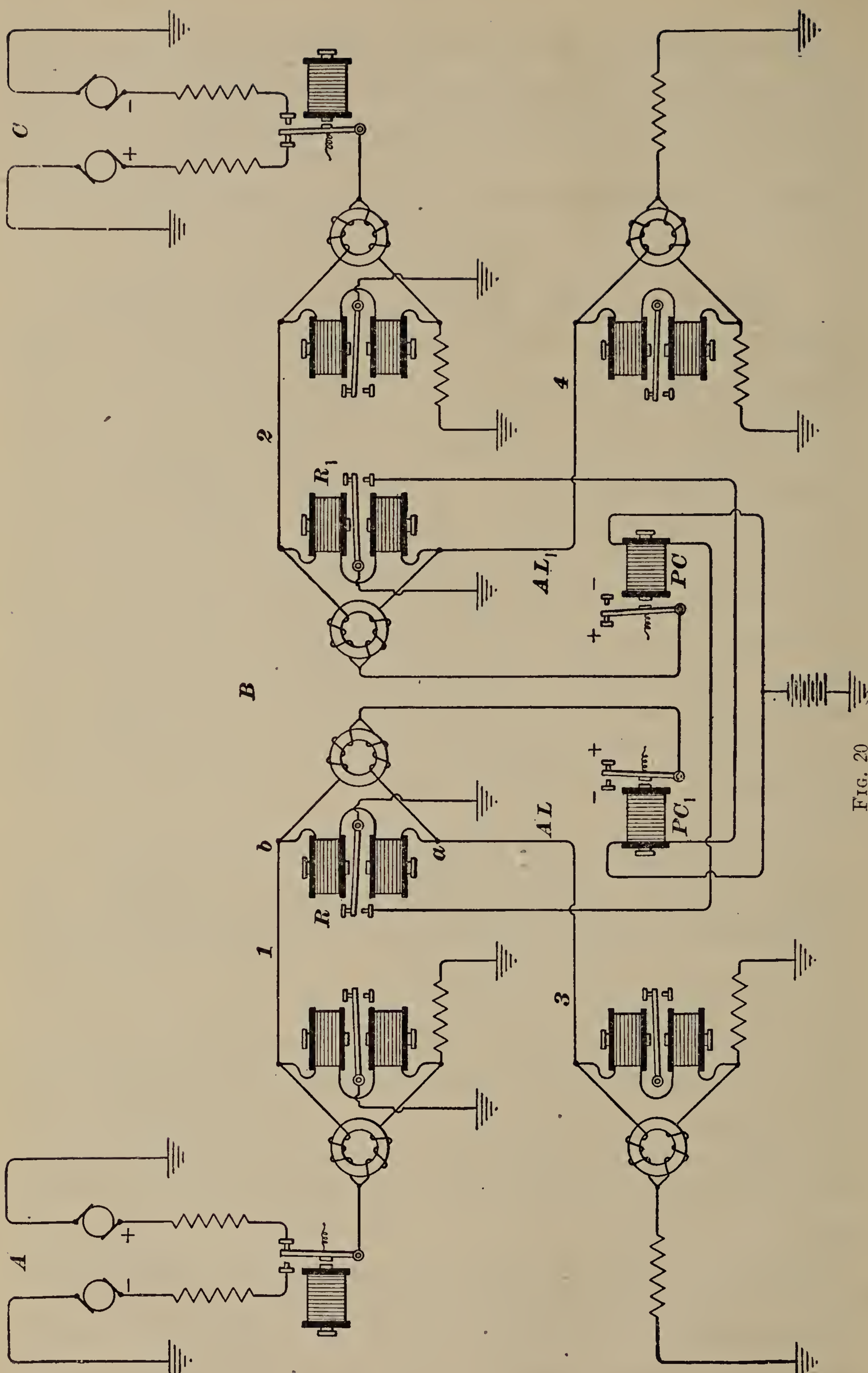


Fig. 20

capacity, and inductance of the current path from point *a* through the artificial line *AL* are the same as the electrical properties of the ordinary artificial line which it replaces which is the equivalent of the current path from point *b* through line wire *1* and the terminal apparatus connected to wire *1* at station *A*. A similar balanced arrangement is formed at the repeater station *B* for the regular line wire *2* by using as the artificial line AL_1 a spare line wire *4* and a spare duplex set. The artificial line of the active duplex set and the artificial line of the spare duplex set at either of the terminal stations should be adjusted so as to have approximately the same values of resistance and capacity. The spare duplex sets are not used for receiving messages, the messages are read by means of the duplex sets connected to the regular line.

71. Advantages of Self-Balancing.—A new balance of the apparatus is usually necessitated by a change in any or all of the properties of the line circuit, such as resistance, inductance, capacity, and insulation of the line wire. The change is generally due to rain, fog, or dew. The artificial-line apparatus being installed indoors, is not subjected to the effects of moisture as is the line wire. The properties of the artificial-line apparatus, such as, resistance and capacity, remain practically constant while these properties of the exposed line wire vary considerably under different conditions of the weather. If the properties of the line wire change considerably an adjustment of the artificial line must be made to obtain a balanced condition.

When artificial lines are replaced by real wires strung on the same pole line as the duplexed wire, both the regular line wire and the balancing wire are subjected to the same conditions and influences; their resistance, insulation, and capacity values vary equally. Furthermore, as the weather clears and the original values are restored, these changes also take place in both sides of the system at the same time, thus automatically maintaining a balance without attention at the repeater station. With the connections shown in Fig. 20, the attendant at either of the terminal stations *A* or *C* is required to adjust the artificial line at his station in order to maintain balanced conditions.

This arrangement is advantageous only when spare line wires are available between the terminal stations and the repeater stations and the balancing wire used is of the same metal and size as the wire operated, so that it will have the same electrical characteristics.

The principle of self-balancing can be applied to two terminal stations by substituting for the artificial line of the active duplex set at each station a spare line wire and a spare duplex set. There will then be one regular line wire and two balancing line wires between each station and an active and a spare duplex set at each station.

SINGLE-BATTERY DUPLEX SYSTEMS

MORRIS SINGLE-BATTERY DUPLEX

72. The **Morris single-battery duplex**, invented by R. H. Morris, of the Western Union Telegraph Company, requires a main-line battery only at one end. The general arrangement of the apparatus is shown in Fig. 21. The instruments are the same as those used in the duplex and quadruplex systems. An ordinary continuity-preserving transmitter is used at the battery station as a pole changer, in preference to one of the walking-beam pattern, in order that the benefits of a continuity-preserving device may be obtained. Where a low electromotive force is used, a transmitter connected as a pole changer may be beneficially substituted for the ordinary dynamo walking-beam pattern, as the tendency to spark will be small.

73. Distinctive Feature of Morris Duplex.—One distinctive feature of the Morris duplex lies in the use of a differential relay, called a **neutral relay**. However, this relay is not used differentially, and is practically a single relay because the current never passes differentially through the two coils. Thus, one current does not neutralize the effect of the

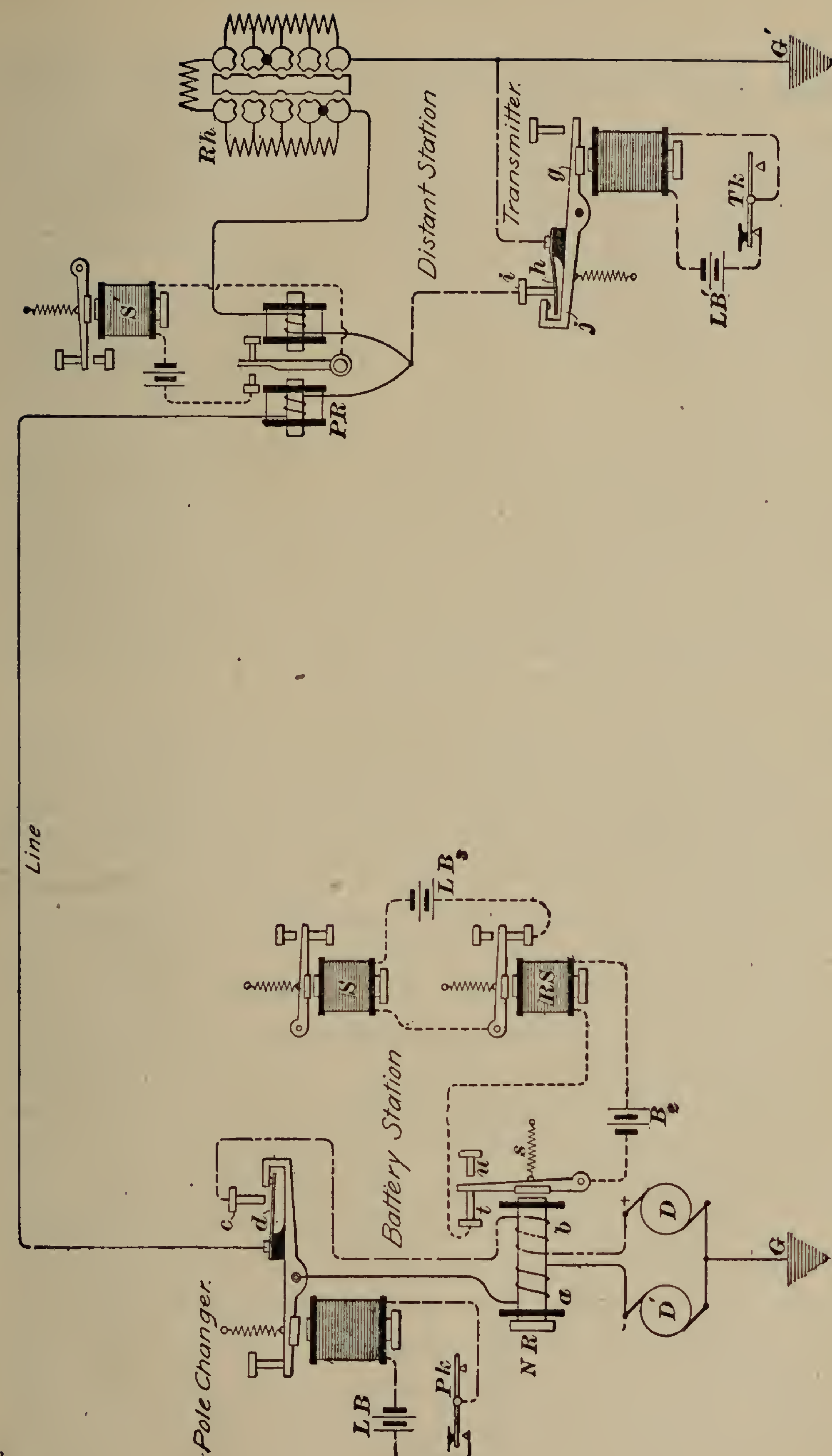

Line
Pole Changer
Battery Station
Distant Station
Transmitter
LB
Pk
NR
a
b
c
d
t
u
s
D
D'
G
S
RS
LB_3
B_2
PR
S'
Rh
g
h
i
j
LB'
Tk
G'

Fig. 21

other. Moreover, the direction in which the cores are magnetized is never reversed. The coils are so wound and connected that when current from the negative dynamo D', Fig. 21, circulates through the coil a, the iron is magnetized in the same direction as when current from the positive dynamo D circulates through the coil b. When the pole changer shifts the line from one coil of the neutral relay to the other coil, there is a moment when the two dynamos are in series and no current passes over the line. At this time there is quite a strong current through both coils of the neutral relay, but the current is in such a direction through the two coils as to preserve the existing direction of the magnetization of the relay. Hence, the magnetization of the neutral relay does not even fall to zero, much less does it reverse when the pole changer is in operation. Consequently, the magnetization produced at reversal, tides the relay over the period of reversal and thus avoids the kick that is so objectionable.

74. This duplex system contains an adjustable resistance Rh. When the transmitter at the distant station is closed, this resistance and the one coil of the polar relay PR are short-circuited and the line is connected through one coil of the polar relay and through the transmitter to the ground G'. When the transmitter is open, both coils on the polar relay and the resistance Rh are connected in series between the line wire and the ground G'. The resistance Rh is so high that when it is in the circuit, the current is reduced to one-fourth the strength that it possesses when the transmitter is closed. But both coils of the polar relay are in series when the transmitter is open and the current passes through the two coils in such a direction that they help each other, and the magnetization produced is still sufficient to operate the polar relay when the current is reversed by the pole changer at the battery station.

The spring of the neutral relay is so adjusted that when the transmitter at the distant station is closed, the current is strong enough to overcome it and attract the armature. But when the distant transmitter is opened the resistance Rh is included in the circuit, consequently the current is reduced to about one-fourth its previous strength, and the magnetism produced in the netural relay is not sufficient to overcome the spring, and hence the armature is released. Therefore, the neutral relay can be closed only by increasing the strength of the current to four times its smaller value and its operation is entirely independent of the direction of the current. On the other hand, the polar relay is operated by reversing the direction of the current and is independent of the strength of the current used.

75. Arrangement of Sounders.—At the battery station, a repeating sounder *RS*, Fig. 21, has its circuit closed when the relay armature is against its front stop, and the ordinary, or reading, sounder *S* has its circuit closed when the armature of the repeating sounder is against its front stop. The arrangement of these two sounders at the battery station is such as to avoid any danger of a false signal when the pole changer short-circuits the two dynamos through both coils. When the distant transmitter is closed, causing the neutral-relay armature to rest against the front stop *t*, the increase in the magnetization of the neutral relay, due to the short-circuiting of the dynamos, can do no harm. Furthermore, experience with this duplex has shown that, even when the distant transmitter is open, the increment of current in the neutral relay, when the two dynamos are short-circuited, does not produce a false signal. This may be due to the fact that the duration of the short-circuiting is much less than the time required for the second coil of the neutral relay, which is empty, to build up from zero. Moreover, it would be necessary, before a false signal could be produced on the sounder *S*, for the armature of the neutral relay to move from the back stop *u* to the front stop *t* and for the armature of the repeating sounder to move from its back to its front stop. This movement requires time. Whatever may be the true explanation, the short-circuiting at the pole changer is so brief that no false signals are produced. It is a disputed point as to whether a repeating sounder is necessary. However, the apparatus was originally set up that way.

OPERATION OF MORRIS SINGLE-BATTERY DUPLEX

76. Both Keys Open.—Let both keys *Tk* and *Pk*, Fig. 21, be open, then the armature of both relays *NR* and *PR* will be resting against their back stops and the sounders *S* and *S'* will be open. The negative dynamo *D'* will be sending current through coil *a*–pole changer–line–both coils of the polar relay *PR*–resistance *Rh*–ground *G'* and back through the ground to the negative dynamo *D'*. The direction of this current is such that the polar relay is held open, and because the resistance *Rh* is in the circuit, the strength of the current is not sufficient to overcome the retractile spring *s* of the neutral relay; hence, the neutral relay is also open.

77. Key *Pk* Closed.—Closing key *Pk*, Fig. 21, closes the pole changer and thus shifts the line from the negative dynamo *D'* to the positive dynamo *D* and reverses the direction of the current throughout the circuit. The neutral relay will not be affected, because the strength of the current is the same as before, but the polar relay will be closed. Hence, by closing the key *Pk* at the battery office, a signal is produced at the distant office only.

78. Both Keys Closed.—If, while the key *Pk*, Fig. 21, is closed the key *Tk* is also closed, the transmitter will close and short-circuit the resistance *Rh* and one coil of the polar relay, while the current will increase to four times its former strength. Although there is now only one coil of the polar relay in the circuit, still the current has been sufficiently increased in strength to more than make up for the fewer number of turns in the coils of the polar relay; moreover, closing the key *Tk* does not reverse the direction of the current. Hence, the polar relay is not affected and remains closed as long as the battery-station key *Pk* remains closed. But increasing the current to four times its former value closes the neutral relay *NR* at the battery station. Hence, both relays are closed when the two keys are closed.

79. Key *Tk* Closed.—If now the key *Pk*, Fig. 21, is opened, *Tk* remaining closed, the line will be shifted from the

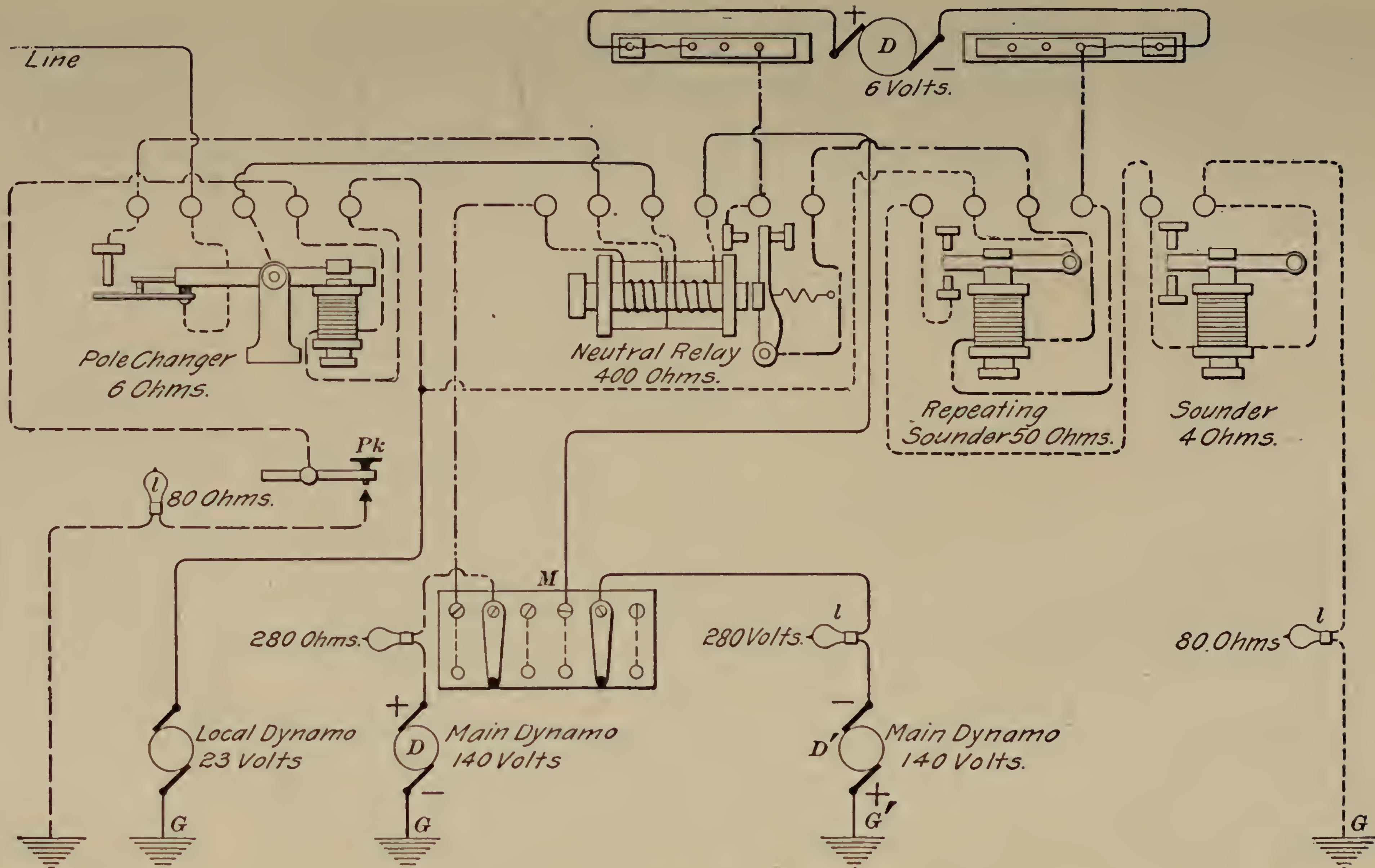

Line
6 Volts.
Pole Changer
6 Ohms.
Neutral Relay
400 Ohms.
Repeating
Sounder 50 Ohms.
Sounder
4 Ohms.
Pk
80 Ohms.
M
280 Ohms.
280 Volts.
80 Ohms
Local Dynamo
23 Volts
Main Dynamo
140 Volts
Main Dynamo
140 Volts.
G
G
G'
G

FIG. 22

positive to the negative dynamo. This will reverse the direction of the current, through the circuit, without causing any change in its strength, and, hence, only the polar relay will be opened. Therefore, the key at one station controls only the relay at the other station, and the operation of a key at one station does not interfere with the signals that are being received by the relay at the same station.

80. Balancing Morris Duplex.—The Morris single-battery duplex is balanced at the battery station by simply adjusting the retractile spring of the neutral relay so that the armature will properly respond to the signals from the distant station, at the same time that the battery-station key is being operated. The polar relay at the distant station requires no adjustment after its armature has been properly centered. The resistance *Rh* is so adjusted as to make the maximum current four times as great as the minimum.

81. Connections of Morris Duplex.—The actual connections of the apparatus at the two offices are shown in Figs. 22 and 23. The two arms of the switch *M*, Fig. 22, are turned to the left when the apparatus is in use. The 50-ohm repeating sounder is supplied with current from a 6-volt dynamo and the other local circuits are supplied, as usual in Western Union offices, from a 23-volt dynamo. Lamps having the proper resistances are connected in the various circuits to help regulate the strength of the current. No primary batteries are used at the battery station, and at the distant office only enough gravity cells to operate the transmitter and the sounder are required.

LARISH SINGLE-BATTERY DUPLEX

82. The single-battery duplex systems are especially useful between main offices and branch or district offices because the operators at the branch or district offices usually have had no experience with any apparatus more complicated than the ordinary relay, key, sounder, and battery; hence, they are unable to adjust and care for systems having polar relays and transmitters, which is the objection to the Morris single-bat-

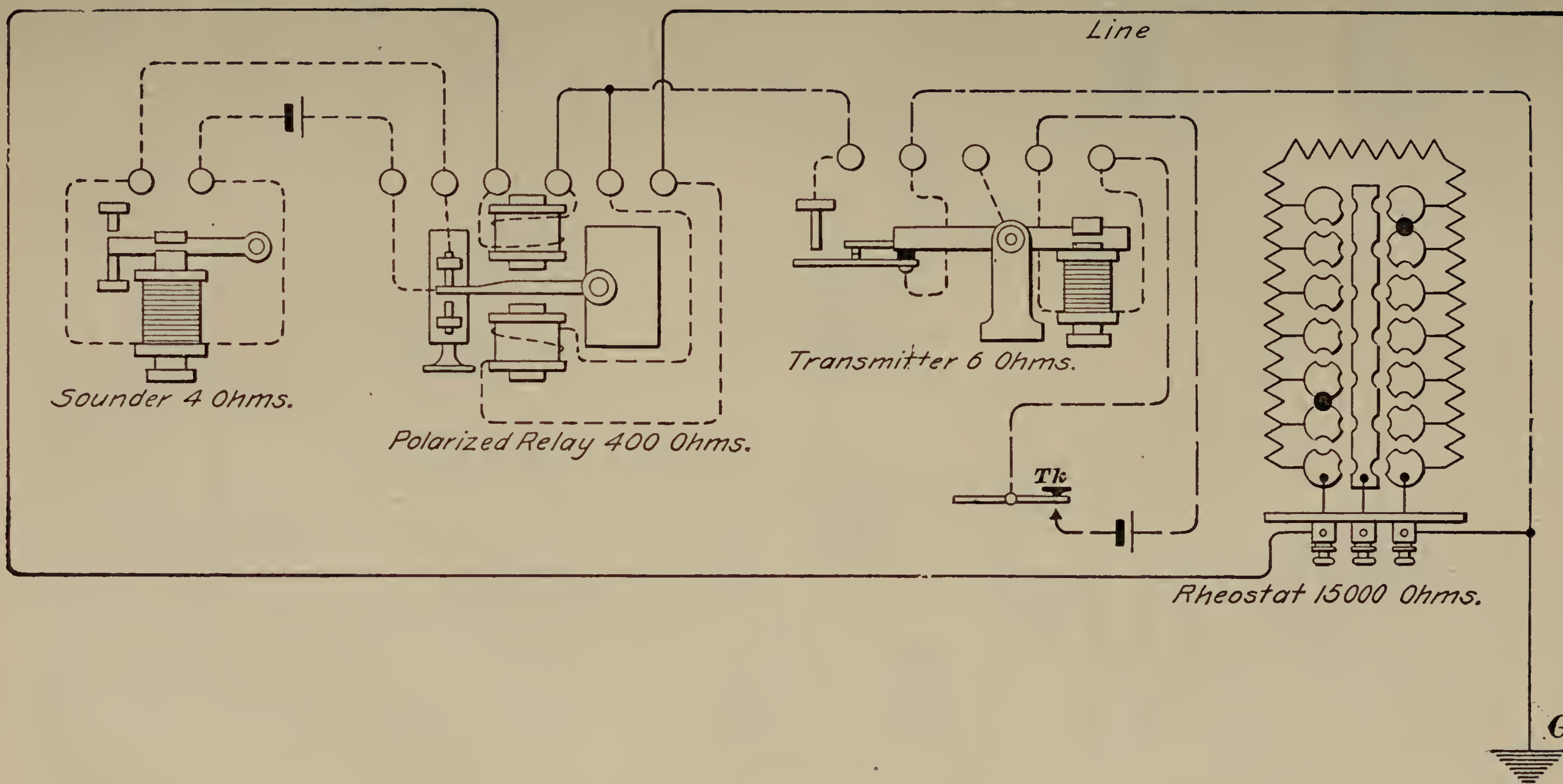

Line
Sounder 4 Ohms.
Polarized Relay 400 Ohms.
Transmitter 6 Ohms.
Tk
Rheostat 15000 Ohms.
G

FIG. 23

tery duplex. The **Larish single-battery duplex, or city-line duplex,** as it is called by the Postal Telegraph-Cable Company, eliminates this objection as only a transmitting, or pony, relay, a relay looking like an ordinary 150-ohm relay, and an unadjustable resistance, are necessary in addition to an ordinary sounder, key, and local battery.

In Fig. 24 is shown a simplified diagram of the Larish single-battery duplex system, omitting the local sounders, which are controlled in the usual manner by the relays *R* and *R'*. The branch office contains a relay *R'*, which, to all appearances is an ordinary 150-ohm relay; a pony relay *T'*, which is also

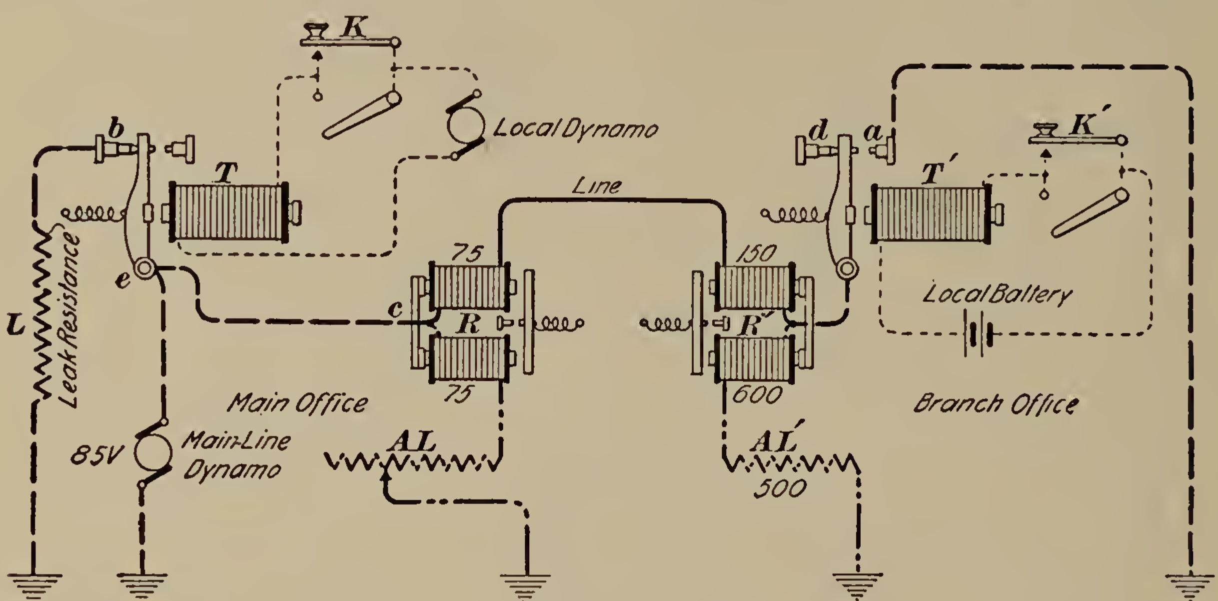


FIG. 24

called a *transmitting relay;* and a 500-ohm resistance *AL'*, which serves as an artificial line. This resistance is placed out of sight in the base of the relay *R'*. One coil of this relay is wound to a resistance of 150 ohms, the other coil to a resistance of 600 ohms. The contact *a* is grounded.

The main office contains an ordinary differentially wound relay *R*, which has two windings of 75 ohms each; an adjustable artificial-line resistance *AL*; a transmitting relay *T*; a leak resistance *L* connected to contact *b*; and a suitable main-line dynamo for supplying current for the line relays *R* and *R'*.

83. Operation of Larish Duplex.—When the main-office key *K* is closed, the lever of the transmitter *T* is against its front stop; therefore, the full voltage of the 85-volt dynamo is applied to the point *c* where the relay *R* is connected to the

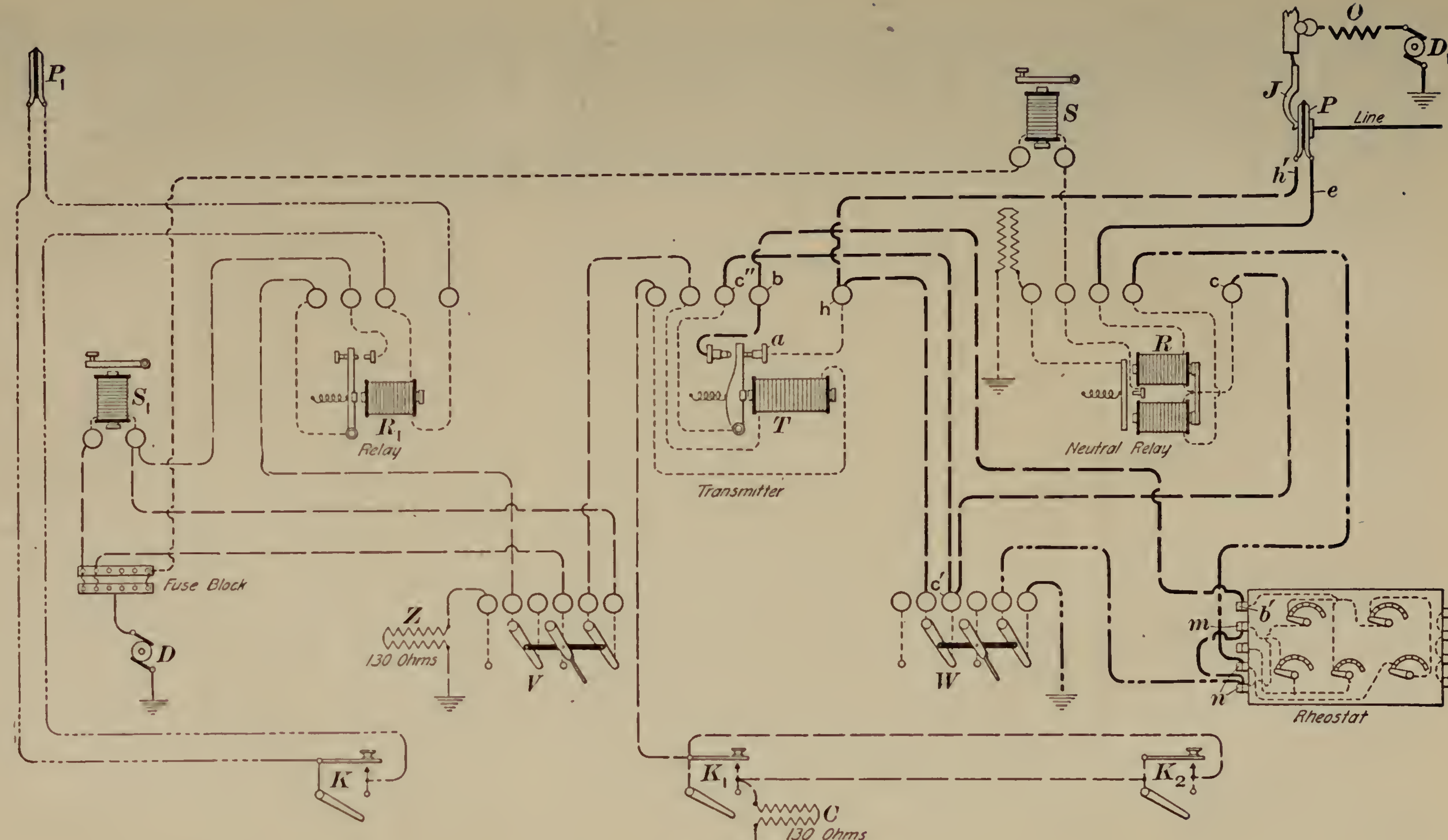

P1
S
S1
O
D1
J
P
Line
h'
e
c''
b
a
h
c
R
R1
Relay
T
Transmitter
Neutral Relay
Fuse Block
D
Z
130 Ohms
V
c'
W
b'
m
n
Rheostat
K
K1
C
130 Ohms
K2

FIG. 25

circuit. When the key K is open, the lever of transmitter T is against its back stop b; sufficient current then passes from the 85-volt dynamo through the leak resistance L to reduce the electric pressure at c to 40 volts. When the branch-office key K' is open and the armature of the transmitting relay T' rests against contact d, the artificial-line resistance AL at the main, or dynamo, office is adjusted until the current divides equally at c whether the voltage is 40 or 85; hence, the operation of the main-office key K has no effect upon the main-office relay R.

But the closing of the main-office key K will operate the branch-office relay R'. For, if the branch-office key K' is open, sufficient ampere-turns will be produced in both windings of the relay R' to make the relay R' attract its armature; and if the branch-office key K' is closed, the 500 ohms in the artificial line and the 600 ohms in one winding of the relay R' will be short-circuited, thereby allowing the current in the 150-ohm coil of the relay R' to increase sufficiently to give enough ampere-turns to cause the relay R' to attract its armature. Thus, the branch-office relay R' will attract its armature only when the main-office key K is closed and it will attract its armature whether the branch-office key K' and transmitting relay T' are open or closed. The resistance and number of turns on the relay R' are so proportioned as to give this desired result.

84. Closing the branch-office key K', thereby cutting 1,100 ohms resistance out of the line circuit, will increase the current through the line coil of the main-office relay R, due to either 85 or 40 volts at c, enough to unbalance the relay R so that it will attract its armature. The closing of the branch-office key K' and transmitting relay T' does not affect the branch-office relay R', because when the main-office key K is open, the 40 volts at c will not produce sufficient current in the 150-ohm winding to cause the branch-office relay R' to attract its armature. When the main-office key K is closed and 85 volts is applied at c, the cutting out of 1,100 ohms still allows enough ampere-turns to hold the branch-office relay R' closed.

85. Practical Diagrams.—In Fig. 25 the connections and apparatus used in the main office are shown. With the

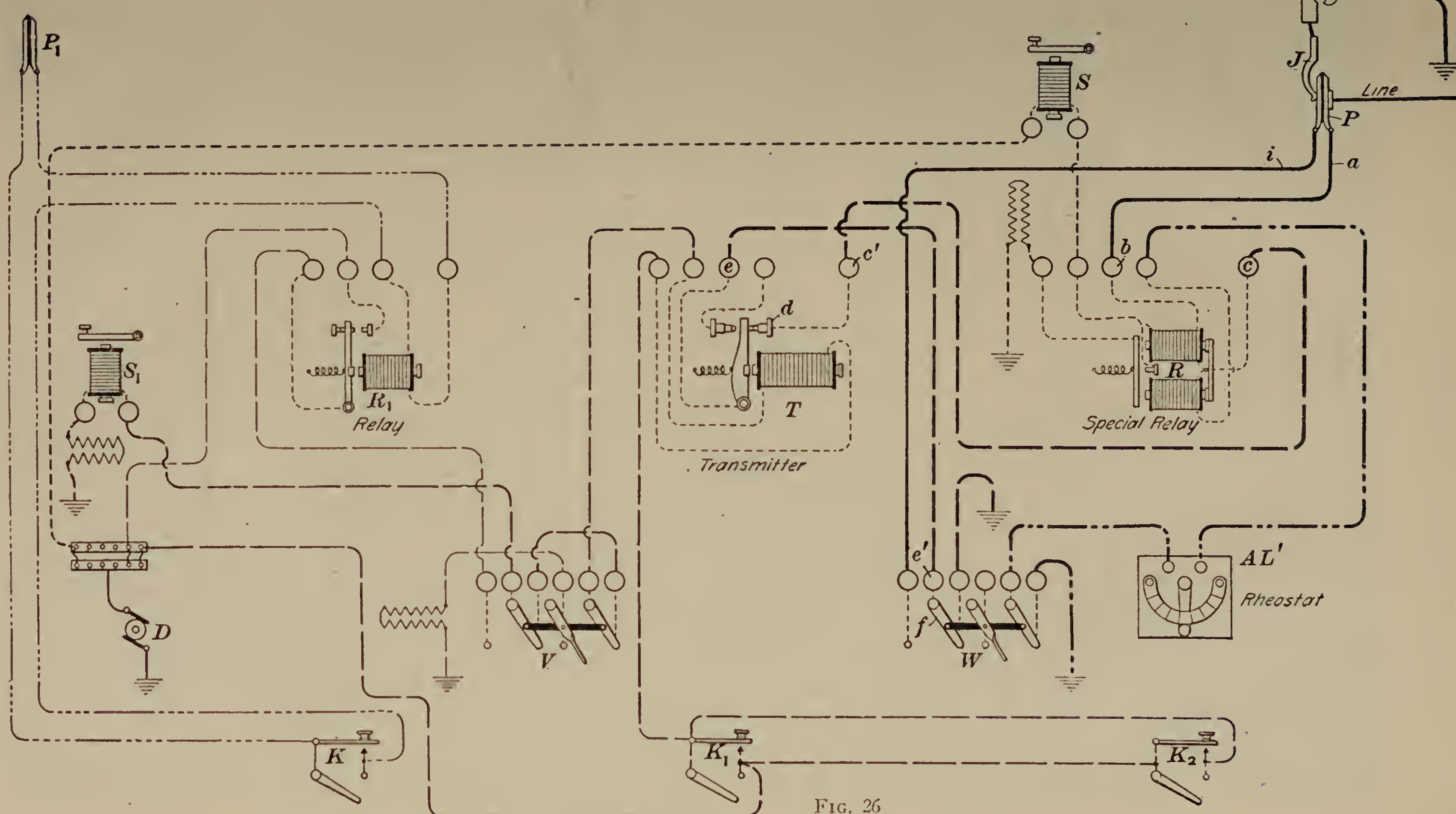

P₁
S
Line
J
P
h
i
a
b
c
c'
d
e
e'
f
S₁
R₁
Relay
T
Transmitter
R
Special Relay
AL'
Rheostat
D
V
W
K
K₁
K₂

Fig. 26

wedge P inserted in the jack J and the switches V and W turned to the right, the apparatus is properly connected to operate as a Larish single-battery duplex. The sounder S is controlled by the differentially wound neutral relay R. The sounder S_1 is in circuit with the magnet of the sending relay or transmitter T, the key K_1 on the sending operator's end of the table, the key K_2 on the receiving operator's end of the table, the 130-ohm resistance C, and the local dynamo D. The key K_2 enables the receiving operator to *break*, that is, open the line circuit, if he does not understand what is being sent him. The sounder S_1 enables the sending operator to read his own signals. The leak resistance is included between the terminals b' and m in the rheostat; the artificial line is connected to terminals n in the same rheostat. The plug P_1 and key K are not in use while the line is duplexed.

86. With the wedge P inserted in a jack as shown, the wedge P_1 inserted in a line jack, and the switches V and W turned to the left, two single line sets are formed. The key K then controls the ordinary relay R_1 and the line in which it is connected; this relay R_1 then controls the sounder S_1, the 130-ohm coil Z and dynamo D being included in this sounder circuit. The other line circuit may be traced through e–one winding of the relay R–c–c'–c''–back stop a–h–h'–wedge P–jack J–switchboard–resistance O–main-line dynamo D_1–ground. The relay R controls the sounder S. There is no key in this line circuit, but either key K_1 or K_2, which are connected in parallel, may be used to control the transmitter T and hence also to send signals through this line. While receiving on the sounder S one or both keys K_1 and K_2 must be closed and while sending with either of these keys K_1 or K_2, the one not in use must be open.

87. In Fig. 26 is shown the arrangement of apparatus for the branch office. With the wedge P in the jack J and the switches V and W turned to the right, the apparatus is properly connected to operate as a Larish duplex system. The relay R controls the sounder S and either key K_1 or K_2 may be used, provided the other is open, to control the transmitter relay T and hence to send signals through the line to the main office. The sounder S_1, which is in series with the local dynamo D and the winding of the transmitter relay T, enables the sending operator to hear his own signals. Although not theoretically necessary, an adjustable resistance AL' is included in the line-relay circuit to assist in regulating the line current; this rheostat may also contain the 500 ohms required in series with one winding of the relay R.

With the wedge P in line jack J, a plug in hole h, the wedge P' in a similar line jack with one side grounded, and the switches V and W turned to the left, two single line sets are formed. The key K then controls the ordinary relay R_1 and the line in which it is connected, and this relay R_1 controls the sounder S_1. The other line circuit, which is controlled by means of the transmitter T and either key K_1 or K_2, provided one of these two keys is open, may be traced through a–b–one winding of relay R–c–c''–contact d–armature of transmitter T–e–e'–switch lever f–wire i–wedge P–jack J–plug at h to ground. The sounder S is controlled by the relay R.

DIPLEX TELEGRAPHY

88. The **diplex** is a system of telegraphy by which two messages may be simultaneously transmitted in the same direction over one wire. The form described here should be thoroughly understood, for it is an essential feature of the quadruplex systems.

The principle of the diplex system may be readily understood by the help of Fig. 27, in which PR is a polarized relay; NR, a neutral relay, so called because its operation depends upon an increase in the strength of the current and not on the direction of the current; PC, a pole changer; and T, a transmitter. The transmitter is so connected that when the key is open, only one cell B' is connected between the wires d and e. When the key is depressed, the lever a first touches the lever b, thereby short-circuiting, momentarily, the battery B, which consists of three cells, before it lifts the moving contact b off the fixed contact c. When the lever a has lifted b off c, the two batteries B and B' are connected in series, making one battery of four cells across the two wires d and e. Hence, the number of cells in the circuit has been increased from one to four; consequently, with the same resistance in the circuit, the strength of the current will be four times as great as before. If the weaker current has a strength of 1 unit, then the stronger current will have a strength of 4 units. That is, the ratio of the two currents is 1 to 4. In order to keep the resistance of the circuit the same whether the battery B is cut in or out, it is necessary to insert the resistance r, which is equal to the internal resistance of the battery B in the circuit when the battery B is cut out.

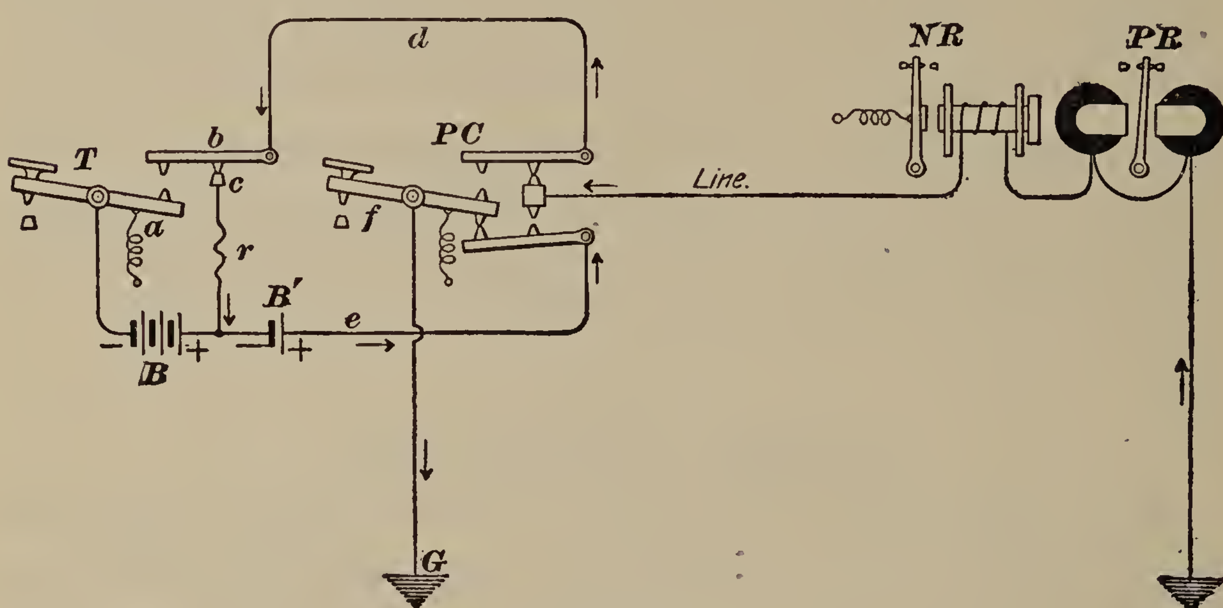


FIG. 27

89. Operation of Diplex System.—When the key f of the pole changer PC is open, that is, up, the line is connected to the wire d, and the ground G to the wire e. When the key is depressed, these connections are reversed. Hence, the pole changer, when operated, reverses the polarity of whatever battery happens to be connected by the transmitter T across the two wires d and e. The operation of the transmitter varies the current from 1 to 4 units, or vice versa, and the pole changer merely reverses the direction of this current through the line whether it is 1 or 4 units. Thus the transmitter and the pole changer do their work independently of one another.

The action of these two instruments when they are combined in this manner should be clearly understood. There are four possible positions of these two keys. If it is not understood that the operation of the pole changer does not affect the strength of the current, and that the operation of the transmitter does not affect the direction of the current in the line, the three other possible positions of the two keys should be drawn on separate pieces of paper and the strength and direction of the current in the line noted in each case. The tongue, or armature, of the polarized relay will move whenever the direction of the current is reversed, no matter whether the strength of the currents is 1 unit or 4 units. The reversal of the 4-unit current will perhaps make the polarized relay operate more vigorously than will the reversal of the 1-unit current, but the 1-unit current will operate it and the intensity of the click of the sounder that is controlled by the polar relay will be the same in either case.

90. The neutral relay, however, will tend to attract its armature no matter in which direction the current passes through it, and if the current is only strong enough to overcome the retractile spring, the relay will close its local circuit. The spring is adjusted so that the magnetism produced by the 1-unit current will not be strong enough to overcome it, but the magnetism produced by the 4-unit current will readily overcome the spring and close the local circuit. Hence the message sent by the operator at the transmitter T, Fig. 27, is received by the operator at the neutral relay NR, and the message sent by the operator at the pole changer PC is received by the operator at the polarized relay PR. Furthermore, these two messages do not interfere with each other when the apparatus is properly adjusted.

91. Elimination of False Signals.—If the pole changer reverses the direction of the current while the 4-unit current is passing, in which case the neutral relay is closed, the neutral relay tends to release its armature at the instant of reversal, because when the whole battery is reversed, and, consequently, the direction of the current through the neutral relay is reversed, the magnetism of the neutral relay must fall to zero before it can increase to its normal strength in the opposite direction. If the interval of no current in the neutral relay, which lasts while the battery is momentarily short-circuited, is sufficiently prolonged, a mutilation of the signal, or a **false signal,** as it is called, will be produced that will seriously interfere with the successful operation of the system. However, by adjusting the pole changer so that the interval of no current in the line and relay is as short as possible, and, furthermore, by using a repeating sounder that is closed on the back stop of the neutral relay, and an ordinary sounder that is closed, in turn, on the back stop of the repeating sounder, the tendency to produce false signals can be overcome. When the local circuit is connected to the back stop instead of to the front stop of the neutral-relay armature, a reduction in the magnetizing force of the relay that will allow the armature momentarily to break away from the front stop will not produce a false signal by closing the ordinary sounder circuit, unless the time interval is sufficient for the relay armature to cross the gap between the front and rear stops, and to make contact with the rear stop. Furthermore, both the repeating sounder and the ordinary sounder require some time before their magnetism can build up from zero to a strength sufficient to start the movement of their armatures. Hence, if the relay armature does momentarily close the repeating-sounder circuit, the duration of contact may be too short to allow the repeating sounder, in turn, to close the circuit of the ordinary sounder. Even if this should happen it may last so short a time that the ordinary sounder cannot build up and make a signal.

92. Reading Sounder.—Whenever a repeating sounder is connected to the back stop of a relay and the signals are to be read by sound, a second sounder must be used. The second sounder must be connected to the back stop of the repeating sounder, otherwise, the signals will be reversed; that is, dots and dashes will be transformed into spaces, and vice versa. This second sounder is frequently called the **reading sounder.**

DUPLEX REPEATERS

Serial 2020 — Edition 1

DUPLEX AND QUADRUPLEX LOCAL-CIRCUIT REPEATERS

GENERAL CHARACTERISTICS

1. In certain systems of duplex and quadruplex repeaters, the local circuits, that is, the sending and receiving local wiring are so arranged by means of cord or plug connections at switchboards, that signals received on a terminal set may be automatically repeated into another duplex set. So far as the operation of repeaters is concerned, what follows applies to all types of duplexes—differential, polar, bridge and modifications of these systems Also, a quadruplex may be regarded as two duplexes on one eline wire, the polar side and the neutral side, each with its own transmitting and receiving instruments.

2. In a duplex system the operator's sending key closes or opens a local-battery circuit which includes the magnet windings of the pole changer or transmitter. The electric impulses sent over the line actuate the distant relay which, in turn, opens or closes a local circuit containing a sounder. If, by means of loop switchboard connections, the local circuit of the receiving relay is connected to the pole changer or transmitter circuit of another duplex, the operation of the relay armature will close or open the transmitting circuit the same as if the local sending key were used for that purpose. Thus, signals received over a line by one duplex may be repeated over another line also duplexed, the operation being automatic at the repeater station.

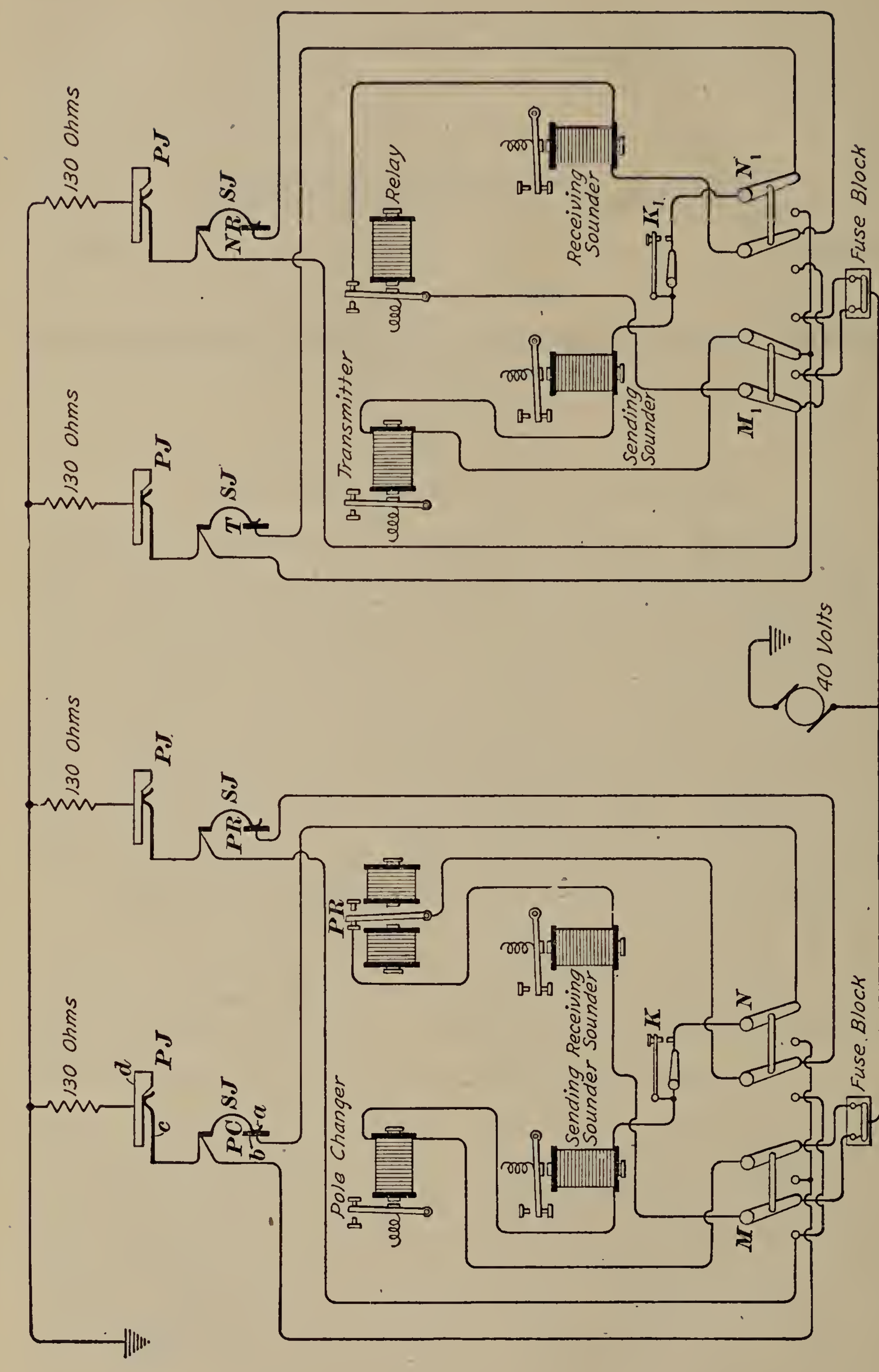

130 Ohms
PJ
SJ
NR
T
PR
PC
a
b
c
d
Relay
Receiving Sounder
Transmitter
Sending Sounder
N_1
K_1
M_1
Fuse Block
40 Volts
PR
Sending Sounder
Receiving Sounder
Pole Changer
N
K
M
Fuse Block

FIG. 1

POSTAL DUPLEX AND QUADRUPLEX LOCAL CIRCUITS

3. Loop-Switch Connections.—Fig. 1 shows the arrangement of local circuits for quadruplex operation used by the Postal Telegraph-Cable Company. The switches, M, N, M_1, and N_1 are situated on the table upon which the apparatus of the quadruplex set is mounted. The circuit of each receiving relay and each transmitting instrument is extended to a loop switch made up of spring jacks *SJ* and pin jacks *PJ*. By means of flexible conductor cords, the various local circuits may be interconnected with the local circuits of other duplexes; these connections may be extended to branch offices, or to operating tables in the same office.

When a double conductor cord with wedge contacts is inserted in the spring jack *SJ* at *PC*, the key connected to the other end of the cord, or at the position to which the cord connection is extended, controls the operation of the pole changer when the switches *M* and *N* are correctly placed. The wedge is inserted between the shank *a*, and the heel *b* of the spring jack. The wedge and its connections are not shown in Fig. 1.

The spring jack is connected to a pin jack *PJ*, the circuit continuing by way of the spring *c* and the frame *d*, through a 130-ohm resistance coil to ground. When it is necessary to remove the ground contact, a hard rubber or fiber insulating plug is inserted in the pin jack which breaks the connection between *c* and *d*.

4. Purpose of Table Switches.—Fig. 2 shows the local circuit of the sending side of a duplex, with the table switches *M* and *N*, Fig. 1, in four different positions. In Fig. 2 (*a*) is shown the circuit resulting when the table switches are thrown to the right. In view (*b*) is shown the circuit when the table switches are thrown to the left. In this case the battery circuit is opened by the switch *M*, Fig. 1, indicating that the set is temporarily out of service.

Fig. 2 (*c*) illustrates the condition of the duplex sending circuit when the table switches *M* and *N*, Fig. 1, are thrown

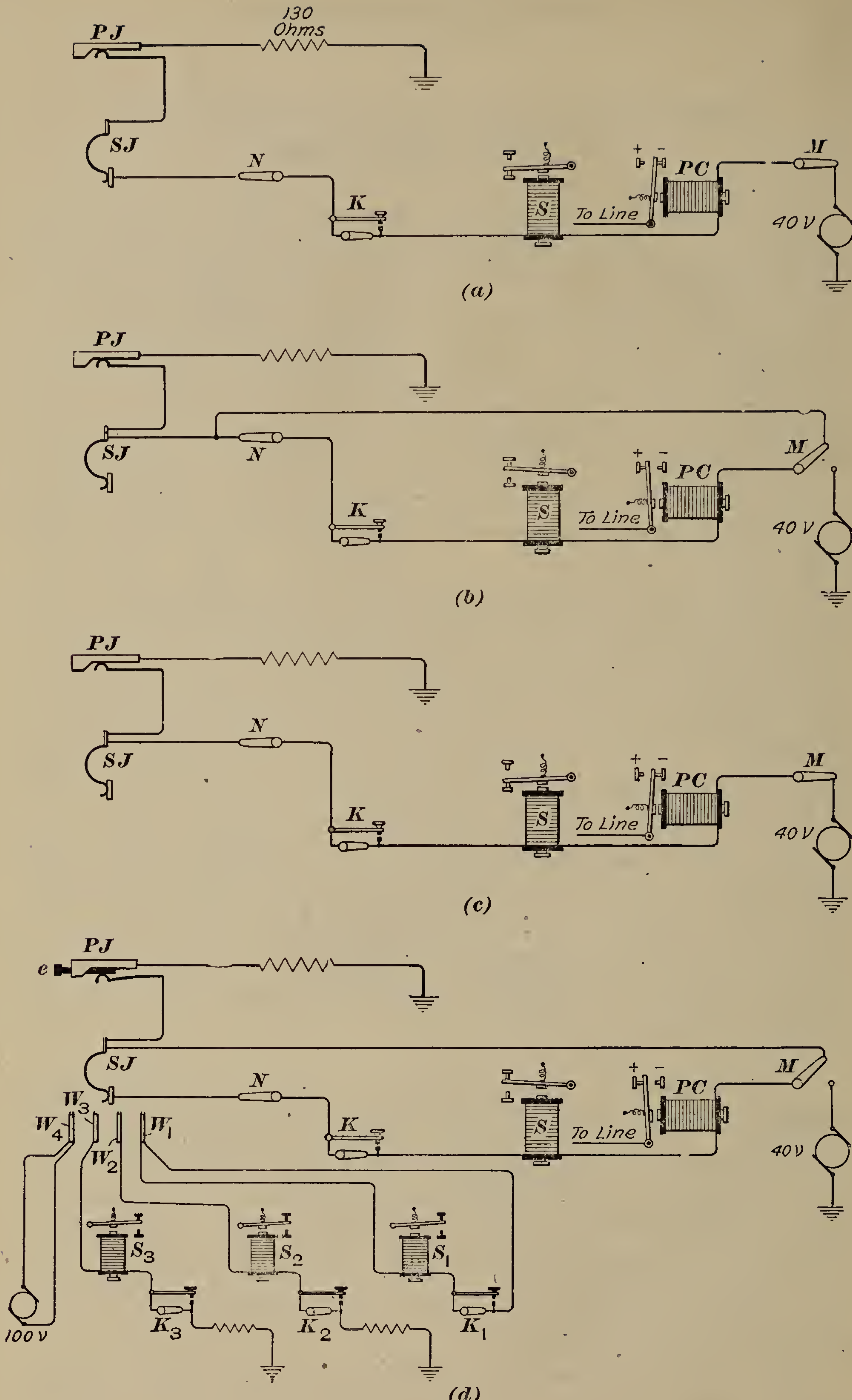

PJ
130 Ohms
SJ
N
K
S
To Line
+ -
PC
M
40 V
(a)
PJ
SJ
N
K
S
To Line
PC
M
40 V
(b)
PJ
SJ
N
K
S
To Line
PC
M
40 V
(c)
e
PJ
SJ
N
K
S
To Line
PC
M
40 V
W_1
W_2
W_3
W_4
S_1
S_2
S_3
K_1
K_2
K_3
100 v
(d)

Fig. 2

toward each other, the switch M to the right, and the switch N to the left. In this case, view (c), the battery circuit is closed, but the control of the pole changer is taken away from any sending key which may be at the time connected to the spring jack SJ. The switches are placed in this position when a quadruplex attendant is called upon by the distant terminal office to balance, or make other adjustments.

In Fig. 2 (d) is shown the circuit resulting when the levers of the switches are thrown apart; the switch M of Fig. 1 to the left, and the switch N to the right. An insulating plug e, Fig. 2 (d), has been inserted in the pin jack PJ, thus removing the ground contact. This places the key, sounder, and pole changer in series with the spring jack, but without battery. This disposition of the switches is necessary when it is desired to connect two or three sending extensions into the local circuit, one or more of these being single and not loop circuits. Key K_1 and sounder S_1 are in a loop circuit connected to a double-conductor wedge W_1. Single-conductor wedge with cord W_2 extends to sounder S_2 and key K_2, thence to ground by way of a resistance coil. Single-conductor wedge with cord W_3 extends to sounder S_3 and key K_3, thence through a resistance to ground. An intermediate battery of 100 volts is connected to a double-conductor wedge W_4 to operate the instruments.

If the four wedges are inserted in the spring jack SJ, in the order in which they are shown in Fig. 2 (d), operators stationed at the four separate keys may alternately send into the duplex circuit, because each of the four keys controls the operation of the pole changer PC. The extension W_1, instead of being connected to a branch office could connect with the receiving-relay local circuit of another duplex and thus become one side of a duplex repeater.

5. Local Circuit of Bug Trap.—As explained in connection with the main-line circuits of the quadruplex, there is a tendency for the armature tongue of the neutral relay momentarily to depart from its front contact when the lever of the pole changer at the distant office passes from one battery contact to the other. Fig. 3 shows the arrangement used by the

Postal Telegraph-Cable Company to prevent false signals on the neutral-side sounder when the line current is changing from one polarity to the other. The relay *BT* is called a bug trap. The local contacts of this relay, not of the line relay *NR*, are extended to the spring jack and pin jack of the loop switch, through which cord connections are made in order to have one set repeat into another.

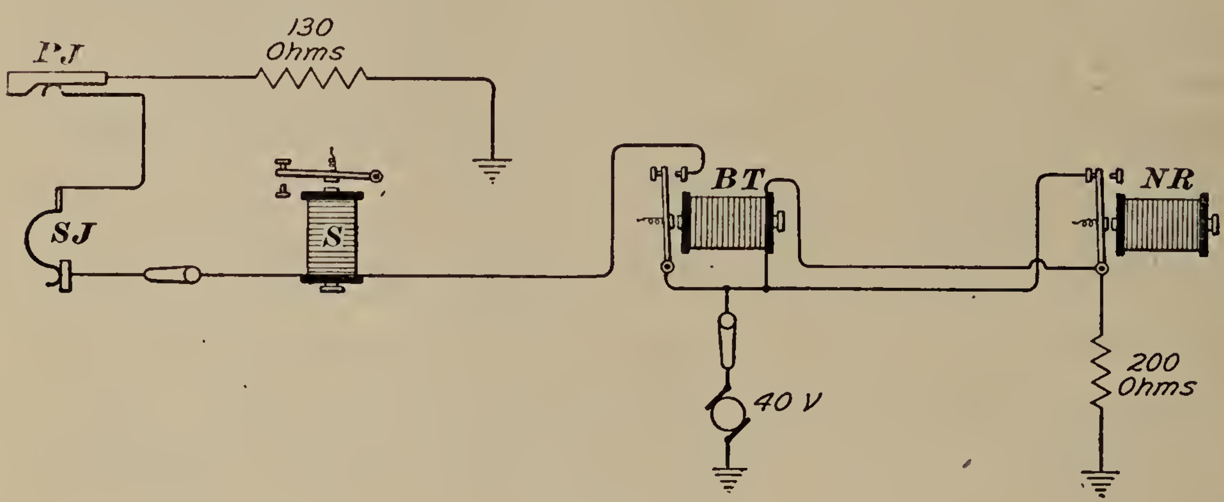


FIG. 3

6. Operation of Bug Trap.—When the armature of the neutral relay *NR* is against its back stop, the winding of the bug-trap relay *BT* is short-circuited; therefore, the armature of the bug-trap relay is against its back stop and the circuit of the reading sounder *S* is open. When the armature of *NR* is against its front stop, the bug-trap relay is energized by current from the 40-volt dynamo passing through the windings of the bug-trap relay and the 200-ohm resistance to the ground. The armature of *BT* is closed and the circuit of the reading sounder *S* is closed. If the armature of *NR* breaks contact with its front stop, due to the action of the distant pole changer in temporarily opening the circuit, the armature of *BT* will remain against its front stop thus keeping the circuit through *S* closed until the armature of *NR* has moved into contact with its back stop. Before this has happened, the pole changer has probably restored the circuit through *NR*.

7. Complete Wiring of Local Circuit.—Fig. 4 shows the complete wiring of the four local circuits of the Postal Telegraph-Cable Company's quadruplex, operated from a 110-volt

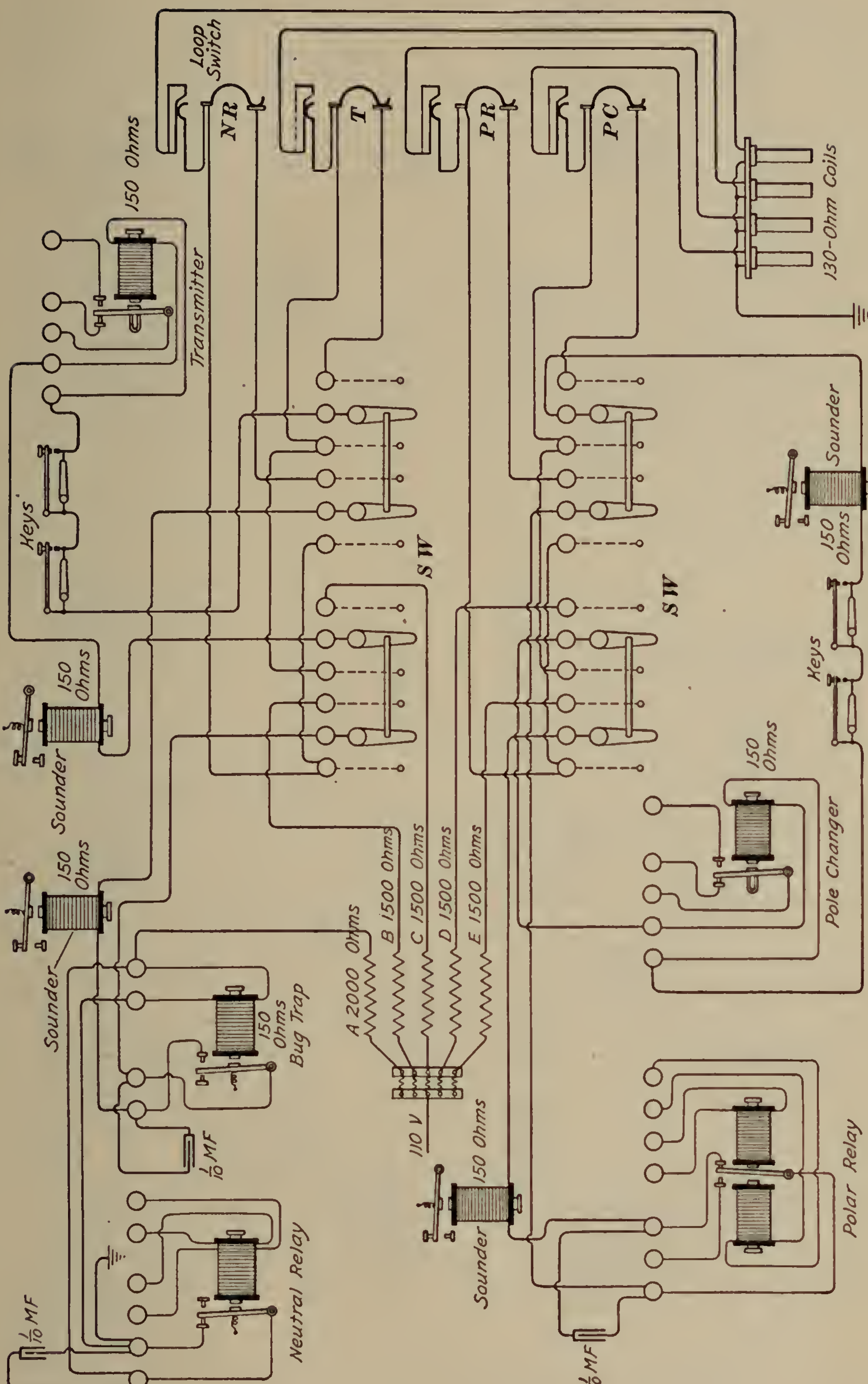

Loop Switch
NR
T
PR
PC
130-Ohm Coils
150 Ohms
Transmitter
Keys
SW
SW
150 Ohms
Sounder
150 Ohms
Sounder
150 Ohms
Bug Trap
1/10 MF
Neutral Relay
1/10 MF
A 2000 Ohms
B 1500 Ohms
C 1500 Ohms
D 1500 Ohms
E 1500 Ohms
110 V
150 Ohms
Sounder
1/10 MF
150 Ohms
Sounder
Keys
150 Ohms
Pole Changer
Polar Relay

FIG. 4

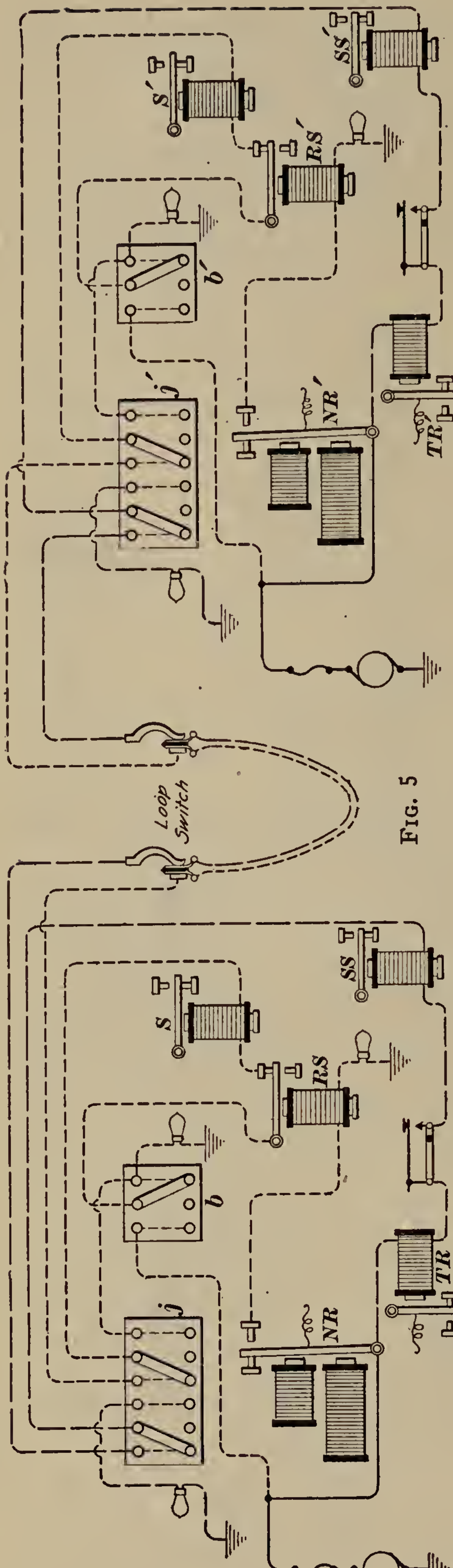

S'
SS'
RS'
b'
j'
NR'
TR'
Loop Switch
S
SS
RS
b
j
NR
TR

Fig. 5

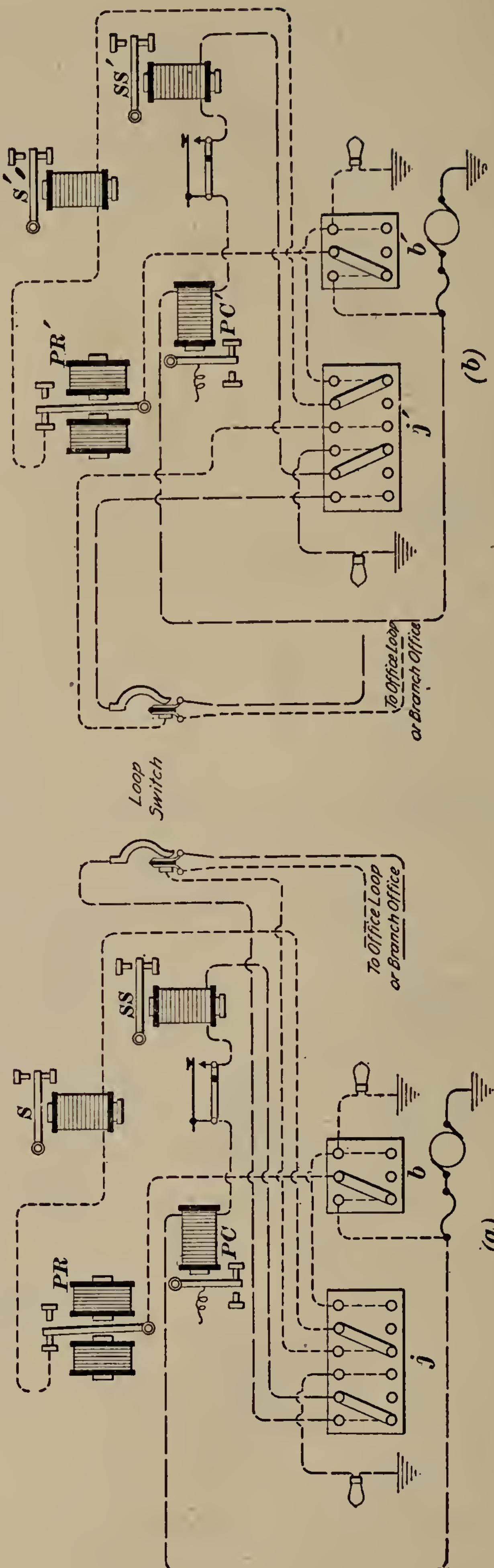

SS'
S''
PR'
PC'
b'
j'
(b)
To Office Loop or Branch Office
Loop Switch
To Office Loop or Branch Office
SS
S
PR
PC
b
j
(a)

Fig. 6

generator. When a 40-volt generator is used, a 600-ohm coil replaces the 2,000-ohm coil *A*; coils *B*, *C*, *D*, and *E* are omitted and 20-ohm transmitters, pole changers and sounders replace the 150-ohm instruments. The duplicate keys are provided so that the apparatus may be operated from different positions.

WESTERN UNION SYSTEM OF DUPLEX AND QUADRUPLEX LOCAL CIRCUITS

8. Figs. 5 and 6 illustrate an arrangement of local circuits in use in many railroad telegraph offices and in the older installations of the Western Union Telegraph Company. In principle the circuits are the same as those previously described.

In Fig. 5 the neutral sides of two quadruplexes are arranged to repeat into each other, the switches *j* and *j′* being turned to the left and switches *b* and *b′* to the right. In Fig. 6 (*a*), the switches *j* and *b* are turned to the left, which is the position for extending the receiving and sending circuits to a branch office; in (*b*), the switches *j′* and *b′* are turned so as to cut off the branch office. By means of the table switches and cord connections at the loop switch, quadruplex local circuits may be interconnected to provide repeater service.

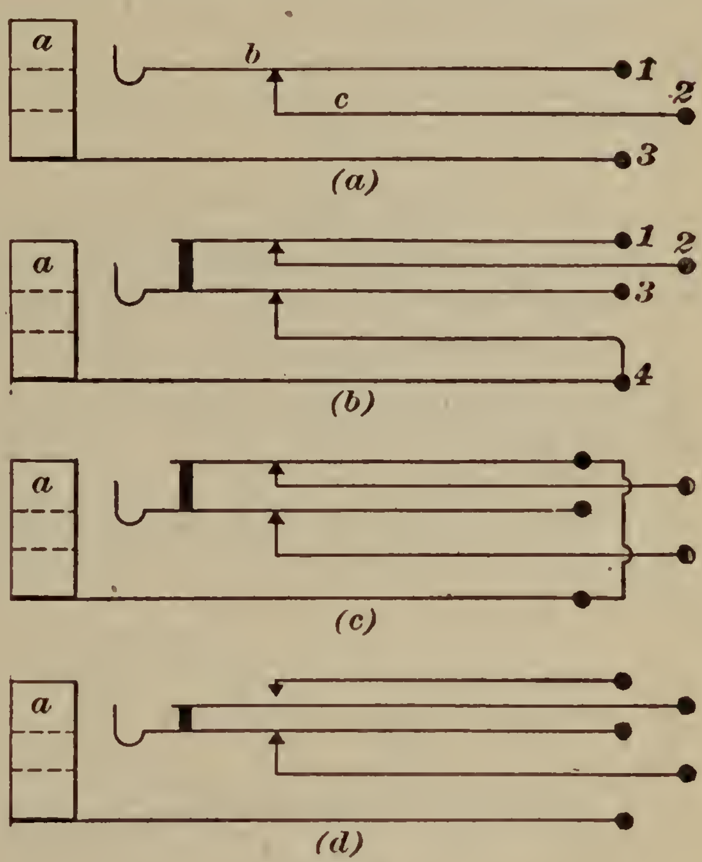


FIG. 7

9. Western Union Loop-Switch Connections.—The pin-jack type of switchboard has been introduced in Western Union terminal offices. Fig. 7 shows four types of pin jacks,

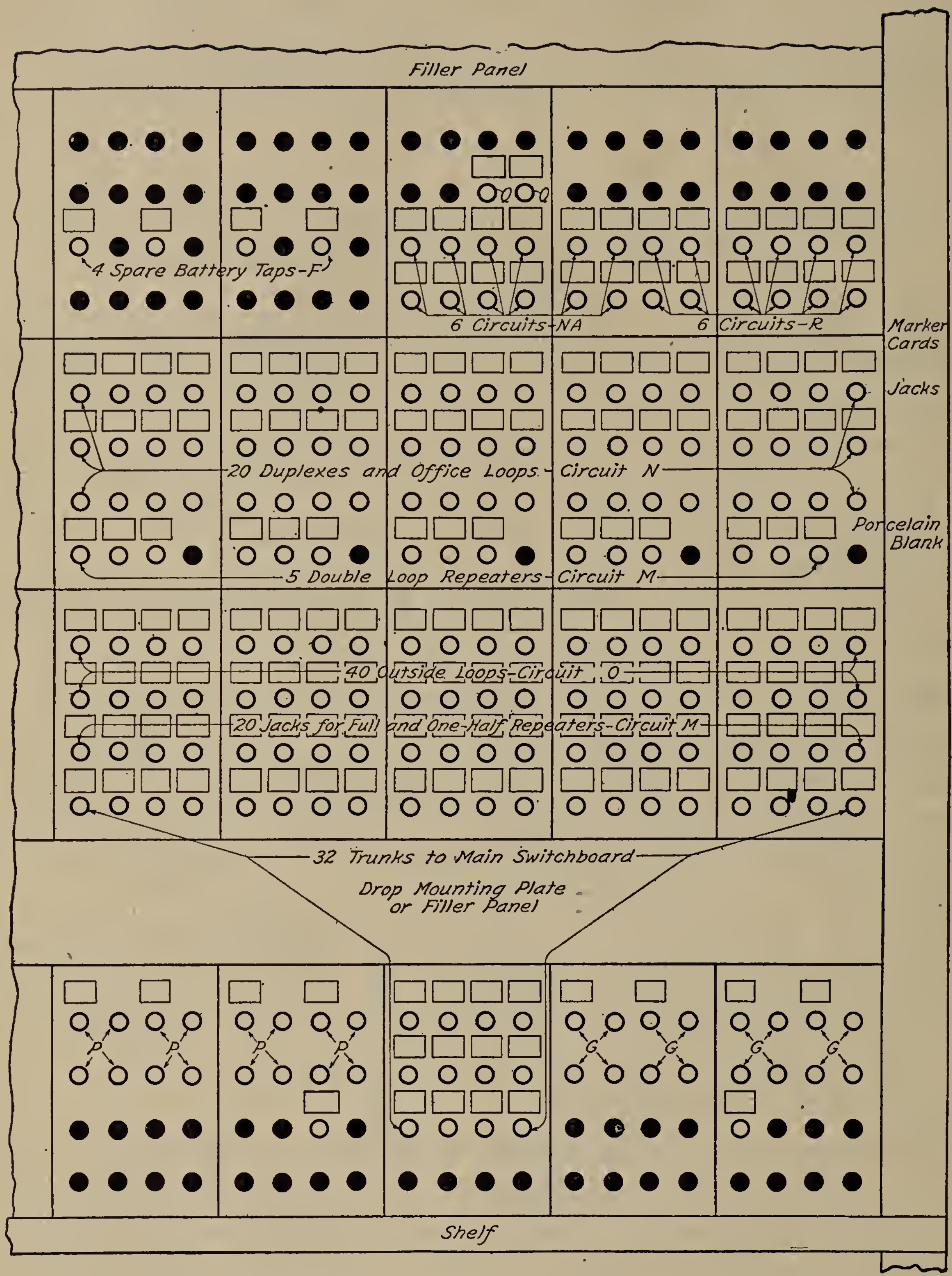

Filler Panel
4 Spare Battery Taps-F
6 Circuits-NA
6 Circuits-R
Marker Cards
Jacks
20 Duplexes and Office Loops-Circuit N
Porcelain Blank
5 Double Loop Repeaters-Circuit M
40 Outside Loops-Circuit O
20 Jacks for Full and One-Half Repeaters-Circuit M
32 Trunks to Main Switchboard
Drop Mounting Plate or Filler Panel
P
G
Shelf

FIG. 8

each designed to perform certain functions. Fig. 7 (*a*) is a two-conductor jack with a circuit-closing spring, when no plug is inserted through the aperture *a*. The insertion of an insulating plug in the jack, opens the contact between *b* and *c*. The insertion of a single-conductor plug in the jack, breaks the contact between *b* and *c*, and joins the plug circuit to the contacts of terminals *1* and *3*. The insertion of a double-conductor plug in the jack connects the plug circuit in series with the contacts of terminals *1* and *3*, and breaks the contact between *b* and *c*. Fig. 7 (*b*) is used in a somewhat similar manner.

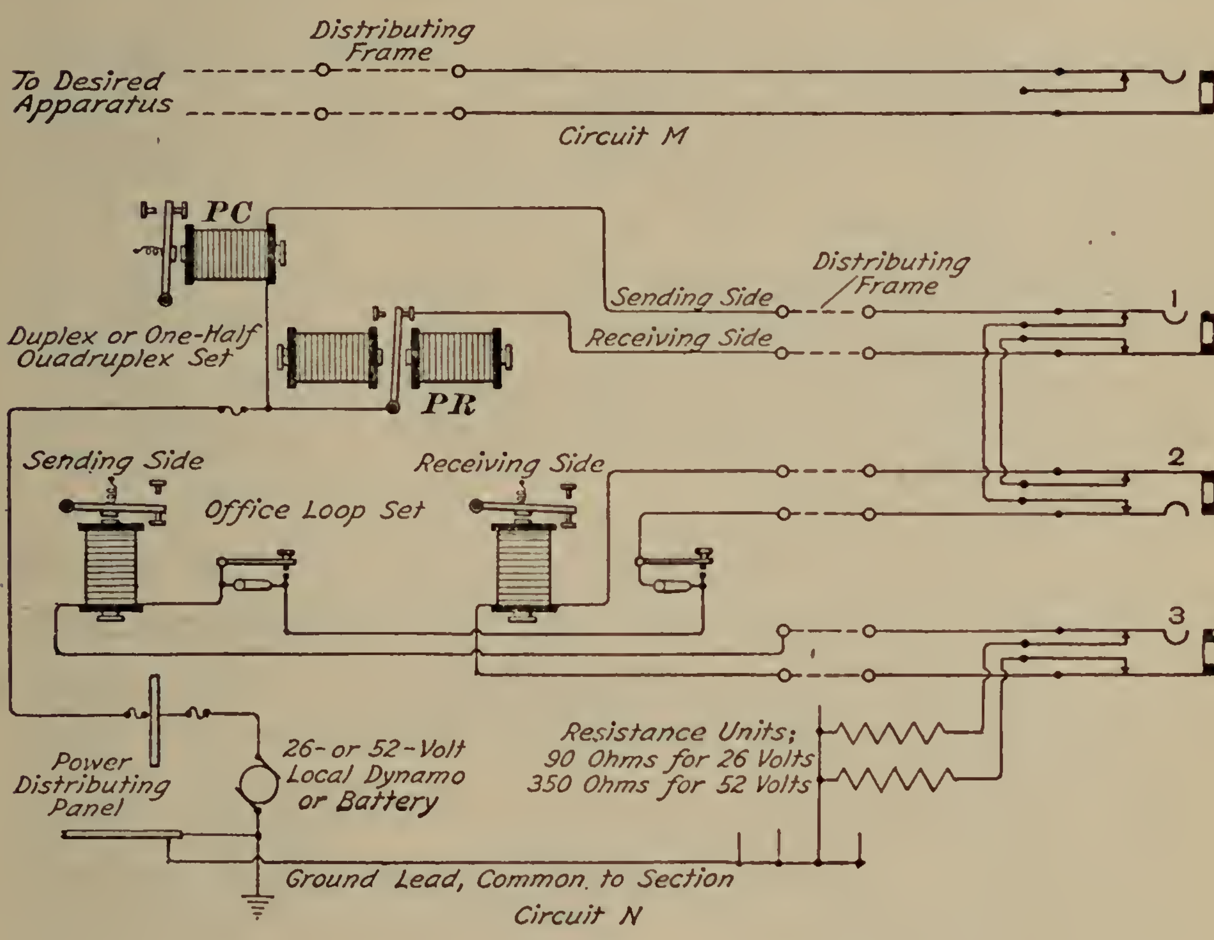


Fig. 9

Fig. 7 (*c*) is used in connection with loops for duplex and quadruplex sets, or other multiplex apparatus. This jack has four spring blades and four external terminals. Fig. 7 (*d*) has five external terminals.

10. Jack Panels of Loop Switches.—In the larger Western Union offices, a special switchboard is provided for the interconnection of local circuits. The main lines terminate at the main switchboard; for local circuits, however, such as those for different operating tables and for subscribers branch offices, a loop switchboard is frequently employed. A panel of a loop switchboard used by the Western Union Telegraph Company is shown in Fig. 8. At the top on the left are shown four spare battery taps *F* for jack and cord connection. These are generally used for testing simplex circuits. On the right at the top are six *NA*-type and six *R*-type circuits. In the center panels, jacks are provided for duplex local circuits, type *N;* double-loop repeaters, type *M;* outside branch-office loops, type *O;* and full single-line repeaters and half repeaters, type *M*.

11. Local Circuits, Type M.—At *M,* Figs. 8 and 9, is shown the type of circuit used for single-line, and double-loop repeaters. Each circuit is provided with a single pin jack which normally stands open. The frame and the contact spring of the jack are wired through a cross-connection distributing frame to the desired operating instrument. For a Morse loop, one such circuit is required; for a full-set repeater, two; for a half repeater, two; and for a double-loop repeater, three such circuits.

12. Local Circuits, Type N.—At *N,* Figs. 8 and 9, is shown the type of circuit used for the sending side and receiving side of locals and duplex sets. This circuit is connected to pin jack *1*. Pin jacks *2* and *3* are normally wired to an operating set in the same office, and to resistance-equalizing units as shown.

13. Local Circuit, Type NA.—The circuit *NA,* Fig. 10, is used where an outside loop is normally operated in connection with a particular duplex set. The loop may be connected to any other duplex set by means of a cord connection between pin jack *2* of this group and pin jack *1* of a similar group, or of a group as indicated in circuit *N,* Fig. 9. Each loop, Fig. 10, used in duplex service is equipped with two equalizing resistance lamps, one in the sending and one in the receiving extension. The purpose of these resistances is to maintain a uniform resistance for all local-circuit extensions, or legs, as they are sometimes called. With a 52-volt local battery, 350-ohm lamps are used, and with a 26-volt battery, 90-ohm lamps are employed, so that sounders will have sufficient operating current. Circuits *N*, Fig. 9, and *NA*, Fig. 10, are used for ordinary duplex and quadruplex operation, the latter, however, being generally used with regular outside loops.

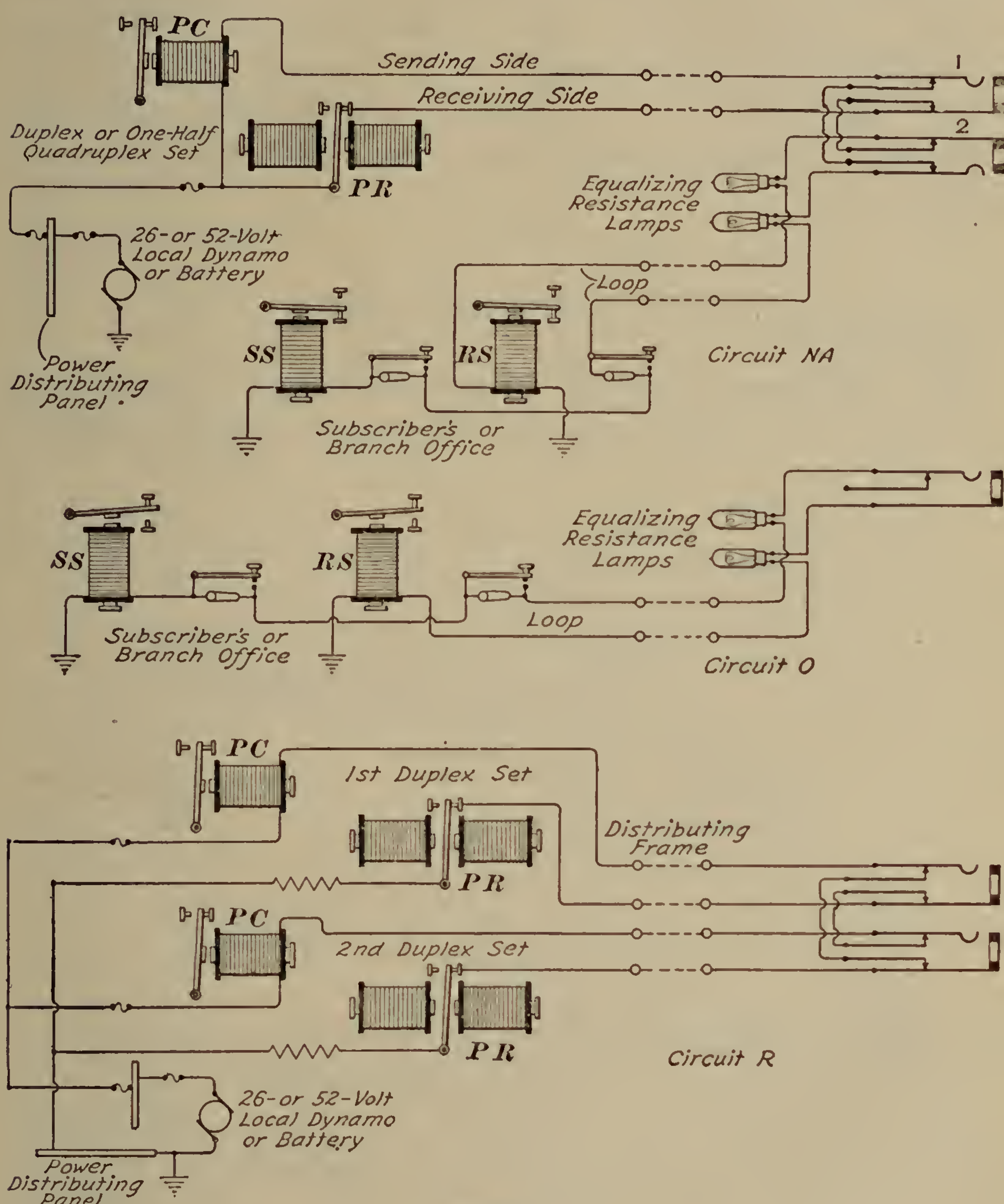


FIG. 10

14. Local Circuit, Type O.—In Fig. 10, at *O*, is shown the loop-switch connections of a duplex loop which has no regular duplex set assignment. It may also replace the sets assigned to *N*, Fig. 9, and *NA*, Fig. 10.

15. Local Circuit, Type R.—The pin-jack wiring of a duplex or a half-quadruplex repeater is indicated at *R*, Fig. 10. The circuit is made up of two pin jacks in which are terminated the locals of the two duplex or half-quadruplex sets constituting the repeater. The normal contacts of these pin jacks are so wired that the normal contact of the spring of each jack is connected to the normal contact of the sleeve of the other jack. The circuit is used for all regular duplex, quadruplex, and multiplex repeaters, except those intended for direct-point repeating.

HALF REPEATERS

16. Purpose of Half Repeater.—Fig. 11 shows three main-line wires from station *A, B,* and *C* connected together

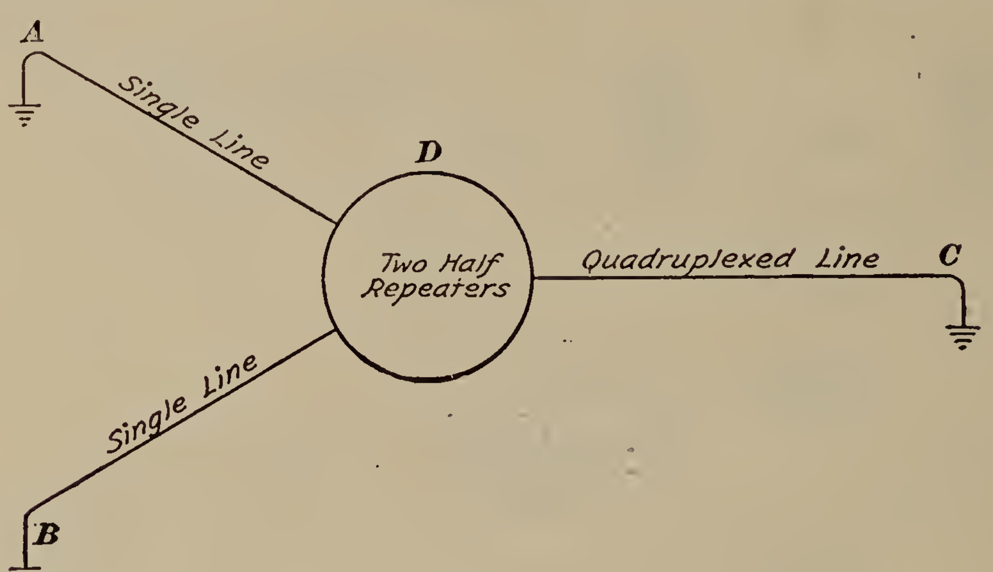
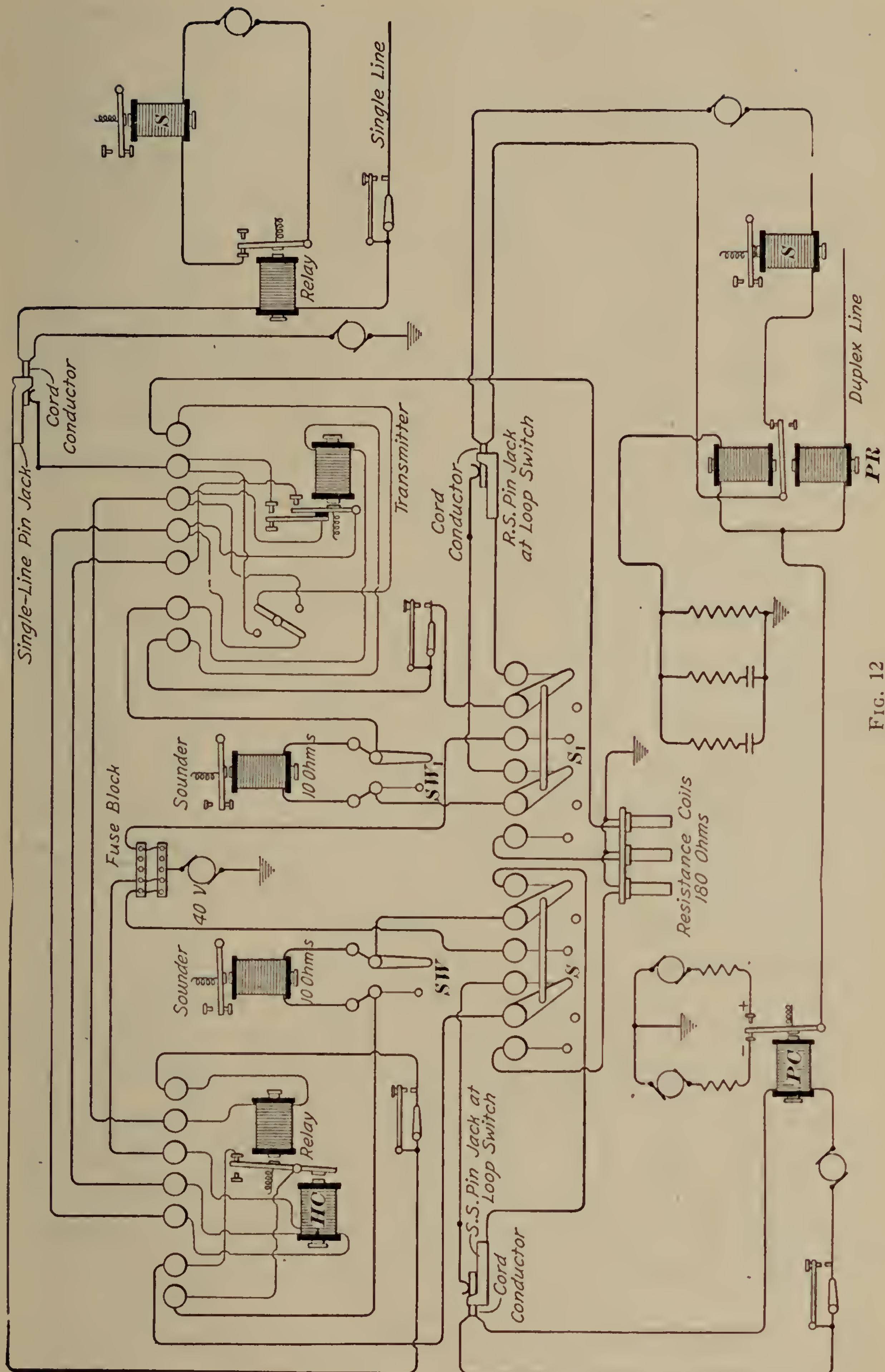


Fig. 11

through half repeaters at station *D*. Between stations *C* and *D*, the line is quadruplex. At the repeater station *D*, the line from *A* may be connected, by means of a half repeater, into the polar side of the line *C–D*, and the line from *B* may be connected into the neutral side of the line *C–D*. By means of a half repeater, any single line, branch line, or newspaper-office loop may be connected into a duplexed line, or one side of a quadruplexed line. A full set of single-line repeaters consists of two repeater transmitters and two repeater relays. A half set consists of one repeater transmitter and one repeater relay.



Single Line
S
Relay
Cord Conductor
Single-Line Pin Jack
Transmitter
Cord Conductor
R.S. Pin Jack at Loop Switch
S
Duplex Line
PR
Sounder
10 Ohms
SW_1
S_1
Fuse Block
40 V
Resistance Coils 180 Ohms
Sounder
10 Ohms
SW
S
+
−
PC
Relay
HC
S.S. Pin Jack at Loop Switch
Cord Conductor

Fig. 12

17. Instrument Connections of Half Repeater. Fig. 12 shows the instrument and loop-switch wiring of a half repeater. The type illustrated is the Weiny-Phillips repeater, used by the Postal Telegraph-Cable Company, the Canadian Pacific Railway Telegraphs, and various railroad telegraph departments. The single-line pin jack is mounted in a panel in the main switchboard where by means of a flexible-cord conductor the jack may be connected to any desired main-line wire. The cord used for this purpose has two conductors with a double plug on one end, and a double wedge on the other. When the wedge is inserted in the spring jack of the main switchboard, one side connects with the line wire by way of the heel of the jack, while the other side, by way of the shank, connects with a main-line battery, one pole of which is grounded.

In Fig. 12, the two loops which extend to the loop switch for connection with the sending side and receiving side of a duplex or a half-quadruplex set, are marked *SS* pin jack, and *RS* pin jack, respectively. When a 110-volt local battery is used instead of a 40-volt battery, the holding coil *HC* of the relay has a 600-ohm resistance coil connected in series with it. Also, the 180-ohm resistance coils are replaced by 1,500-ohm coils, but these are connected near the point where the three wires leave the fuse block, instead of at the ground end of each battery circuit. Transmitters of 150 ohms are used in place of the 20-ohm instruments used with a 40-volt battery.

Normally, the switches S and S_1 are thrown to the right. Throwing the switches to the left cuts off the sending and receiving sides of the duplex and closes the local circuits through the 180-ohm ground coils for operation over the single line only. After the repeater has been adjusted and placed in service, the switches SW and SW_1 may be closed in order to remove from the local circuits the resistance of the sounders. These switches are opened only when it is necessary for the repeater attendant to listen to the character of passing signals.

18. Combination Repeater.—Fig. 13 shows the wiring of a repeater system which may be used as a full-set, single-line repeater, or as two half repeaters. When the four six-point

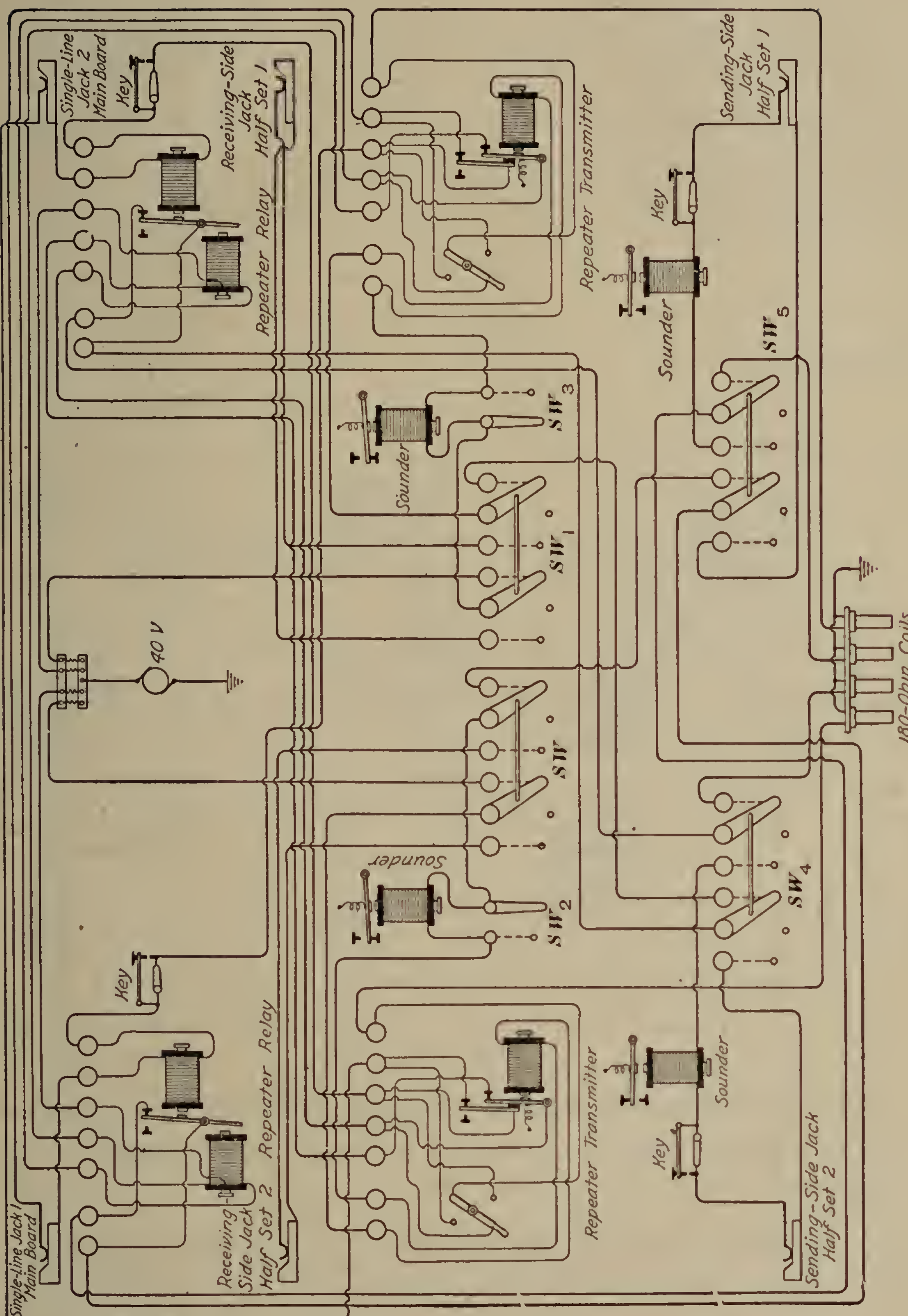

Single-Line Jack 2 Main Board
Key
Receiving-Side Jack Half Set 1
Repeater Relay
Repeater Transmitter
Sending-Side Jack Half Set 1
Key
Sounder
SW 5
SW 3
Sounder
SW 1
40 V
SW
Sounder
SW 2
SW 4
180-Ohm Coils
Key
Repeater Relay
Receiving-Side Jack Half Set 2
Single-Line Jack 1 Main Board
Repeater Transmitter
Sounder
Key
Sending-Side Jack Half Set 2

FIG. 13

switches *SW*, SW_1, SW_4, and SW_5 are thrown to the right, the set is arranged as a single-line repeater; that is, the line connected to single-line jack *1* will repeat into the opposite line in jack *2*. With these switches thrown to the left, the set is divided into two half repeaters. The single-line jacks *1* and *2* at the main switchboard are the points at which the two single lines are connected when the set is used as a full repeater. The sending-side jacks of half set *1*, and of half set *2* are situated in

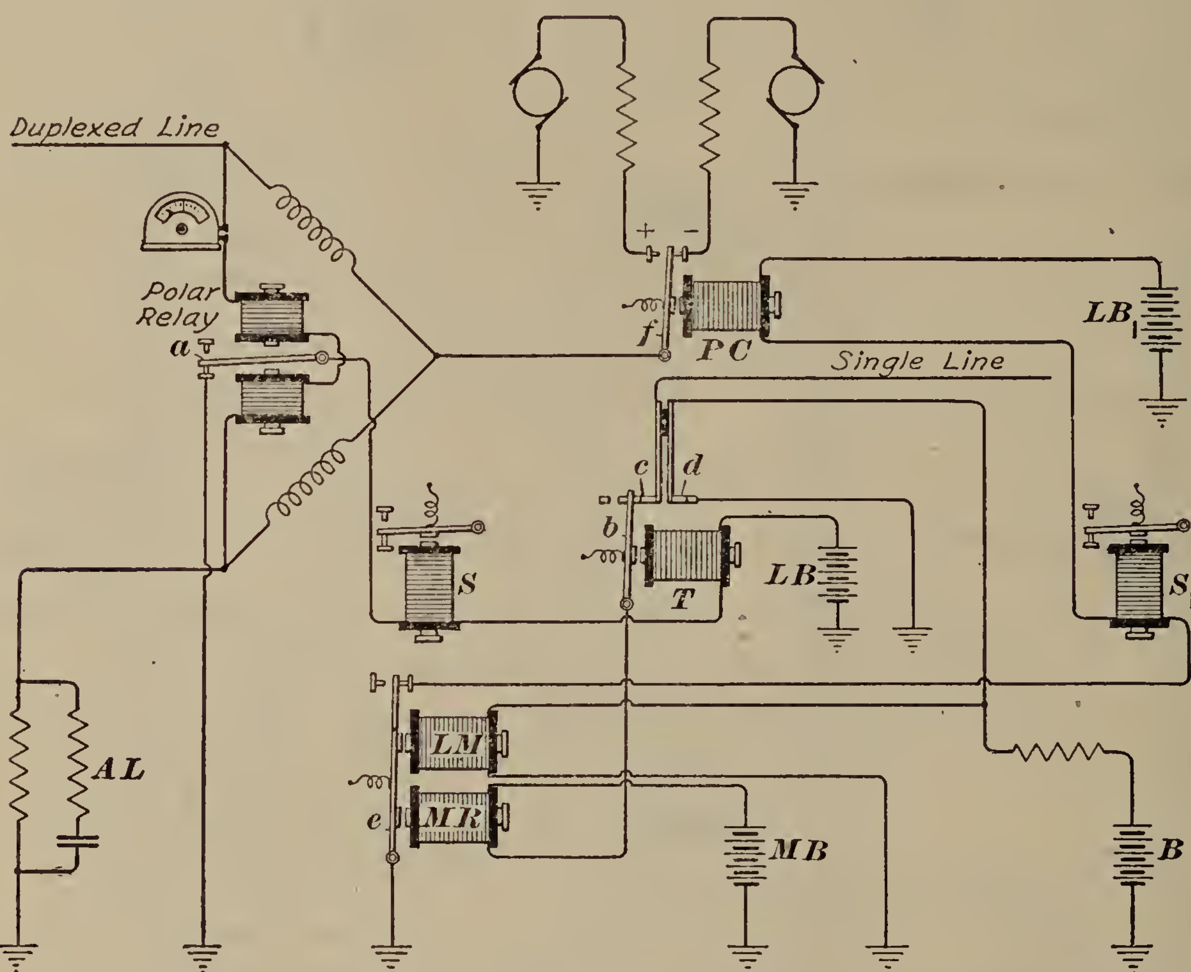


Fig. 14

a panel of the loop switch, as are the receiving-side jacks of half set *1*, and half set *2*. These 4 jacks are for connections to a duplex set.

19. Front-Contact, Shunt-Locking Half Repeater. A half repeater used by the Western Union Telegraph Company and by railroad telegraph departments operated in connection with Western Union lines is illustrated in Fig. 14 and is known as the front-contact, shunt-locking half repeater. The half repeater consists essentially of one set of duplex terminal apparatus and a single-line repeater arrangement made up of a relay with a locking magnet, a transmitter, and the necessary local batteries. Positive and negative electric impulses sent over the duplex line have corresponding effects on the armature *a* of the polar relay at the repeater station. Armature *a* opens or closes a local circuit extending from the grounded contact of the polar relay, sounder *S*; through the coils of transmitter *T* to the grounded local battery *LB*. When the armature *a* of the polar relay makes contact with the grounded stop, the coils of transmitter *T* will be energized and its armature will rest against its front contact, allowing current to pass from the main battery *MB*, through relay *MR*, armature *b*, movable contact *c*, through the single line to the branch office.

There will be no current in the coils of transmitter *T* when the armature *a* of the polar relay is drawn to the open contact. The armature *b* of transmitter *T* will then be released and the two movable contacts, *c* and *d*, will open their circuits. Contact *d* opens a trifle sooner than *c* and opens the shunt around locking magnet *LM*. A moment later contact *c* opens and stops the flow of electricity from battery *MB* over the single line and through the coils of relay *MR*. The locking magnet *LM* is now energized, however, and the armature *e* of relay *MR* will be held in the closed position thereby preventing the repetition of signals back over the duplex line.

Similarly, impulses coming from the branch office over the single line through contact *c* of transmitter *T* operate the armature *e* of the relay *MR*; the position of the armature *e* controls the position of the armature *f* of the pole changer *PC*, allowing current of the proper polarity to pass over the duplexed line. The sounders *S* and S_1 permit the repeater operator to observe the character of the passing signals through the repeater apparatus. It will be noted that the operation of the instruments of a half repeater is the same as described in the Section dealing with single-line repeaters, and practically any one of the single-line repeaters there described may be used as a half repeater for connecting single lines to duplex or half-quadruplex circuits.

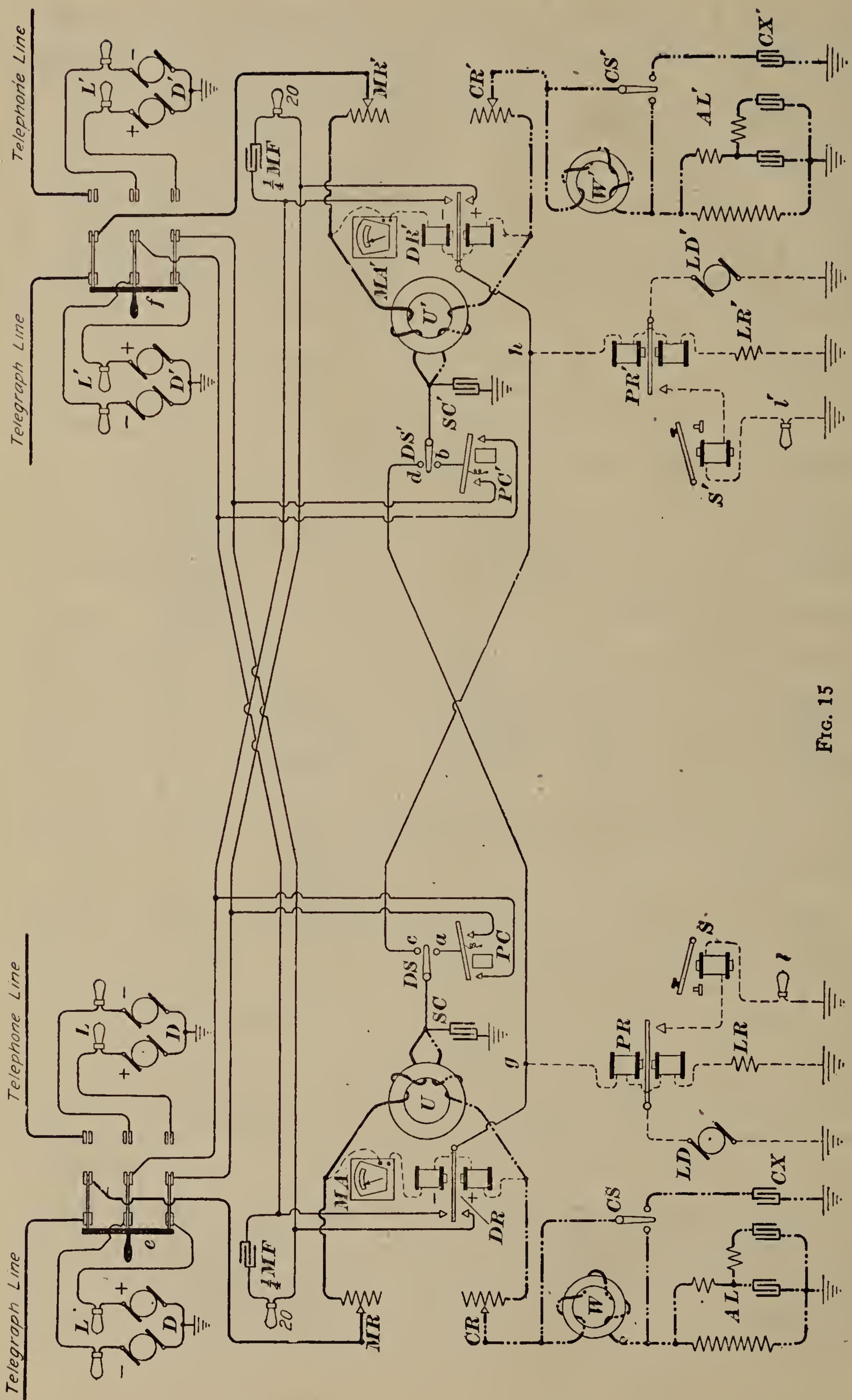

Telephone Line
Telegraph Line
Telephone Line
Telegraph Line
MR
MR'
MF
CR
CR'
CS
CS'
CX
CX'
AL
AL'
W
W'
DR
DR'
MA
MA'
U
U'
SC
SC'
DS
DS'
PC
PC'
PR
PR'
LR
LR'
LD
LD'
S
S'

Fig. 15

FULL-SET REPEATERS

WESTERN UNION BRIDGE DUPLEX REPEATER

20. In Fig. 15 are shown two *polar-bridge duplex sets* arranged to repeat through each other. They can be operated independently for adjustment or for communication with each end from the repeater station. The sets may be used with regular telegraph- or telephone-line wires and their proper electromotive forces. When both dividing switches *DS* and *DS′* are turned to contacts *a* and *b* respectively, two independent duplex sets are obtained; when they are turned to contacts *c* and *d*, one set repeats into the other. The armature of relay *DR* acts to send current impulses over the duplex line at the right, and the armature of relay *DR′* sends impulses over the duplex line at the left. The three-pole, double-throw switches *e* and *f*, when turned to the left, connect the sets to ordinary telegraph wires and dynamos supplying as high a voltage as is commonly used with telegraph lines. When these switches are turned to the right, telephone lines and 110-volt dynamos or storage batteries are used.

21. Leak-Relay Circuit.—In order that the repeater operator may ascertain the character of the signals transmitted to each line by the direct-repeating sets, the two main-line wires are tapped at the tongues of their respective relays at *g* and *h* in Fig. 15, and a small portion of the outgoing currents from each transmitting relay is diverted through a high-resistance leak circuit, in which is connected a sensitive polar relay *PR*, called a *polar-leak relay*, controlling a local sounder *S*.

The regular box form of polar relay with its coils connected in series is used and the leak resistance *LR* is contained in a box, the coils of which range from 8,000 to 20,000 ohms and is so arranged as never to contain less than 8,000 ohms. The leak resistance should be as high as will allow just sufficient current to pass through to operate the leak relay properly, when it is adjusted to work, with the smallest possible current. Otherwise, the main line is deprived of more current than is necessary. The leak relay should be kept properly centered; this can be done without interfering with the passing signals, by throwing the proper lever of the leak box over to the stud marked open and thus opening the leak circuit.

The composite coils *W* and *W′* and the condensers *CX* and

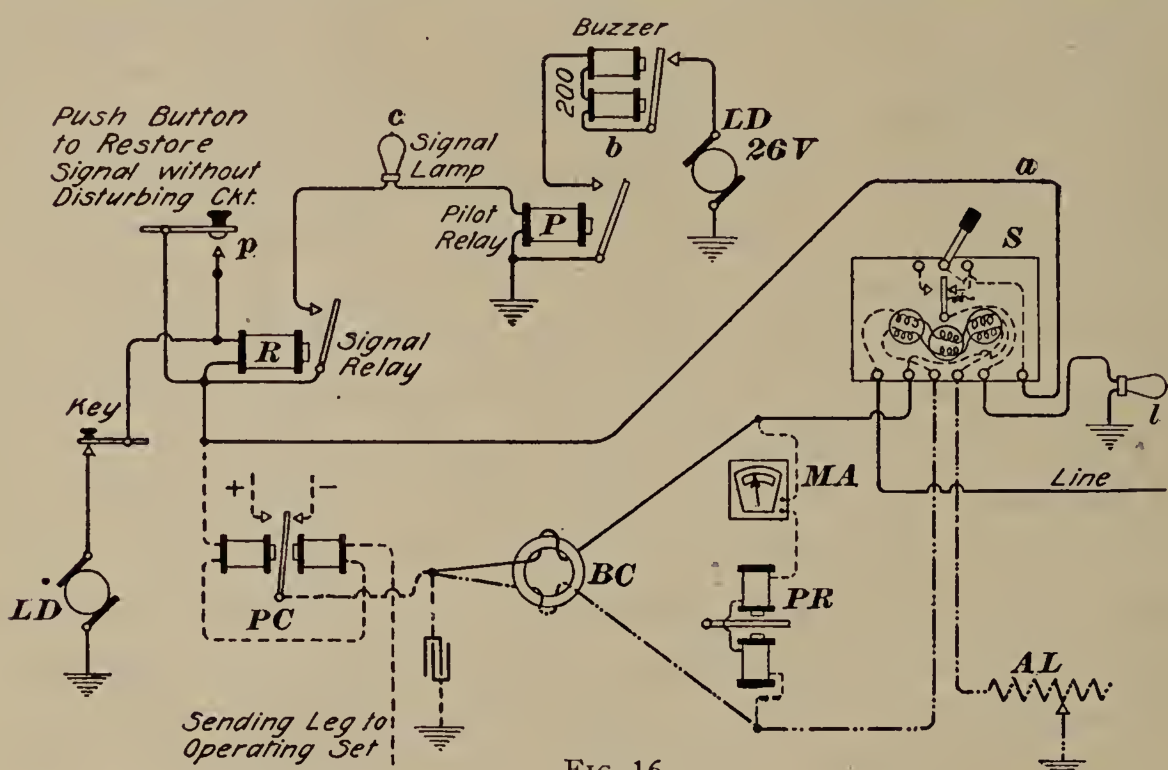


FIG. 16

CX′ are cut out by turning the switches *CS* and *CS′* to the left. They are cut in by turning these switches to the right, which is done only when composited telephone lines are used, in order to balance the inductance and capacity in the composited set to eliminate the sounds of the Morse signals from the telephone receiver. When used with a simplexed telephone line, the switches *CS* and *CS′* should be turned to the left, as the inductance coils *W* and *W′* and the condensers *CX* and *CX′* are not then required to eliminate the Morse signals from the telephone receiver.

22. Signaling Circuits.—In Fig. 16 is shown a repeater attendant's signaling circuit. In the line and artificial line cir-

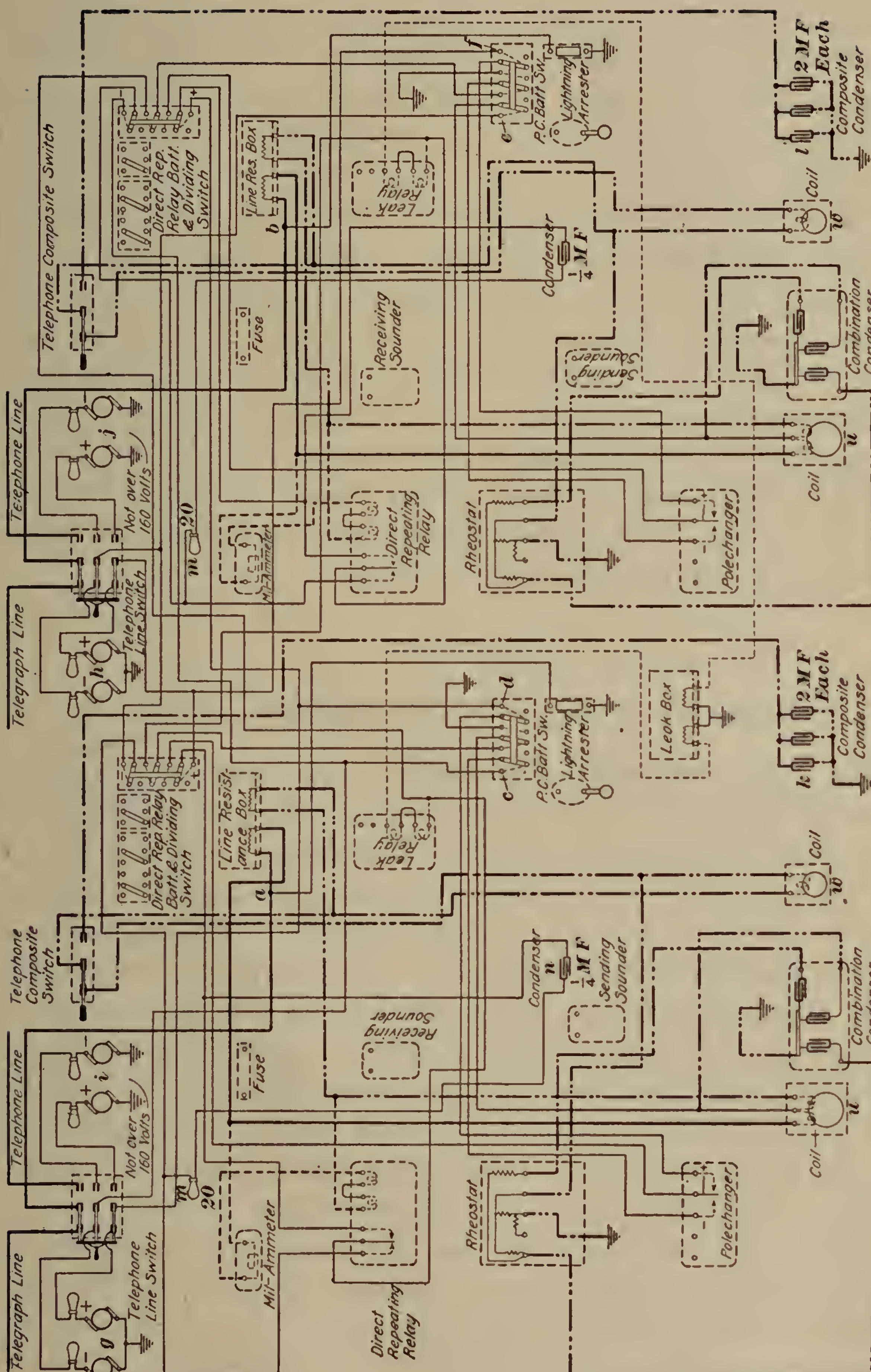

Telephone Composite Switch
Direct Rep. Relay Batt. & Dividing Switch
Line Res. Box
Leak Relay
P.C. Batt. Sw.
Lightning Arrester
2 M F Each
Composite Condenser
Coil
Condenser
$\frac{1}{4}$ M F
Fuse
Receiving Sounder
Sending Sounder
Combination Condenser
Telephone Line
Not over 160 Volts
Telegraph Line
Telephone Line Switch
Mil-Ammeter
Direct Repeating Relay
Rheostat
Polechanger
Leak Box
Line Resistance Box
Direct Rep. Relay Batt. & Dividing Switch
Telephone Composite Switch
20

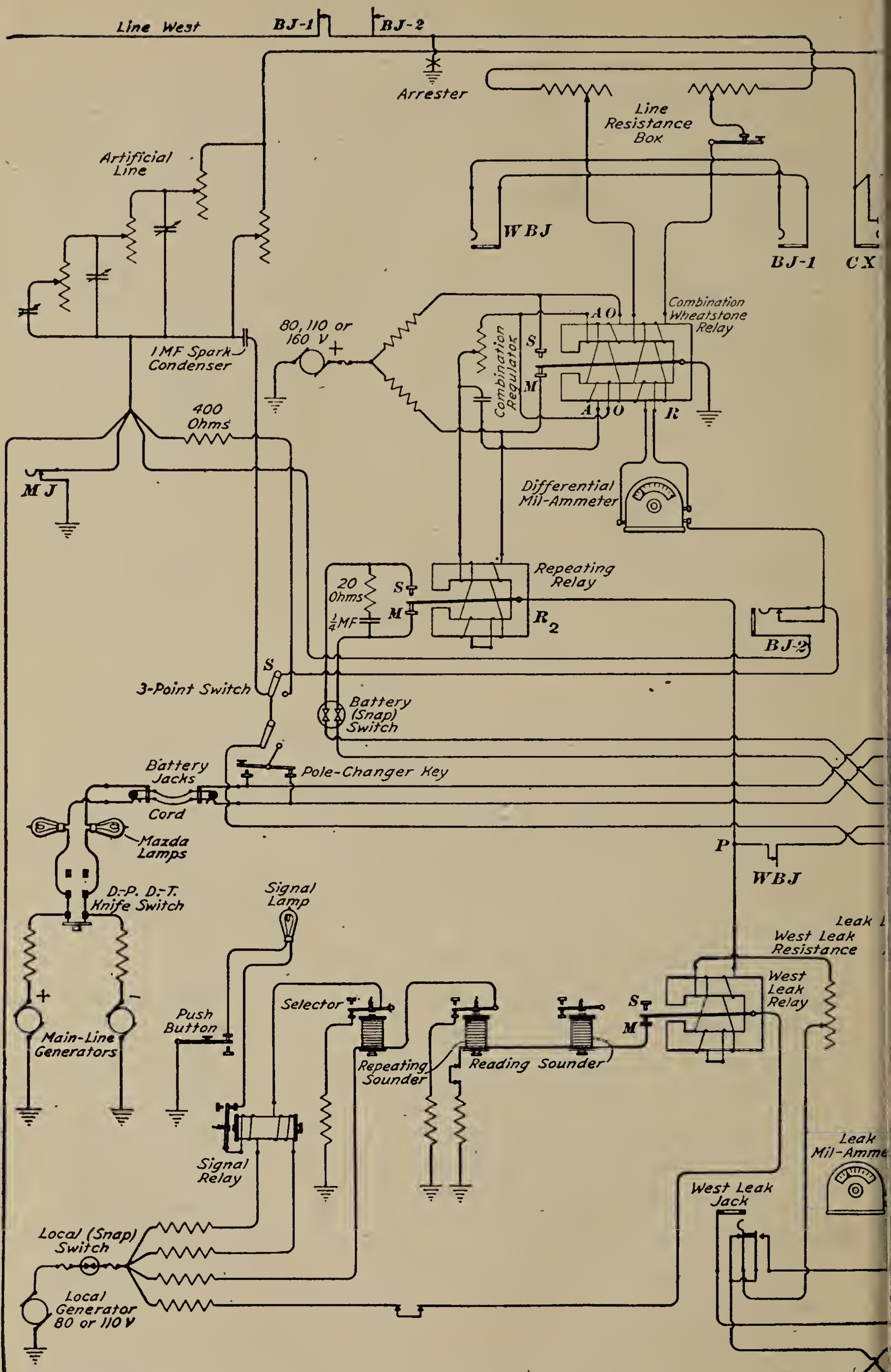
FIG. 17

cuits are included coils of the so-called *neutral signal relay S,* having a single-pole, double-throw switch on the base whereby the wire *a* may be connected to either the front- or back-contact stop of the relay. Equal currents through the coils of this relay will allow the spring to hold the lever against the back stop. If the distant operator opens his line circuit, the current in the home artificial line will operate this signal relay *S,* allowing current to pass through the 60-ohm resistance lamp *l* and closing the signal relay *R,* which is locked in its closed position and allows current to illuminate the signal lamp *c,* to close the pilot relay *P,* and to sound the 200-ohm buzzer *b* until the home operator restores all signals by pressing the push button *p,* which causes the relay *R* to release its armature provided the distant operator has closed his line circuit. Thus, the distant operator has to open the circuit only a moment and the repeater attendant can reply as soon as he is free to do so.

BRIDGE DUPLEX-REPEATER SETS

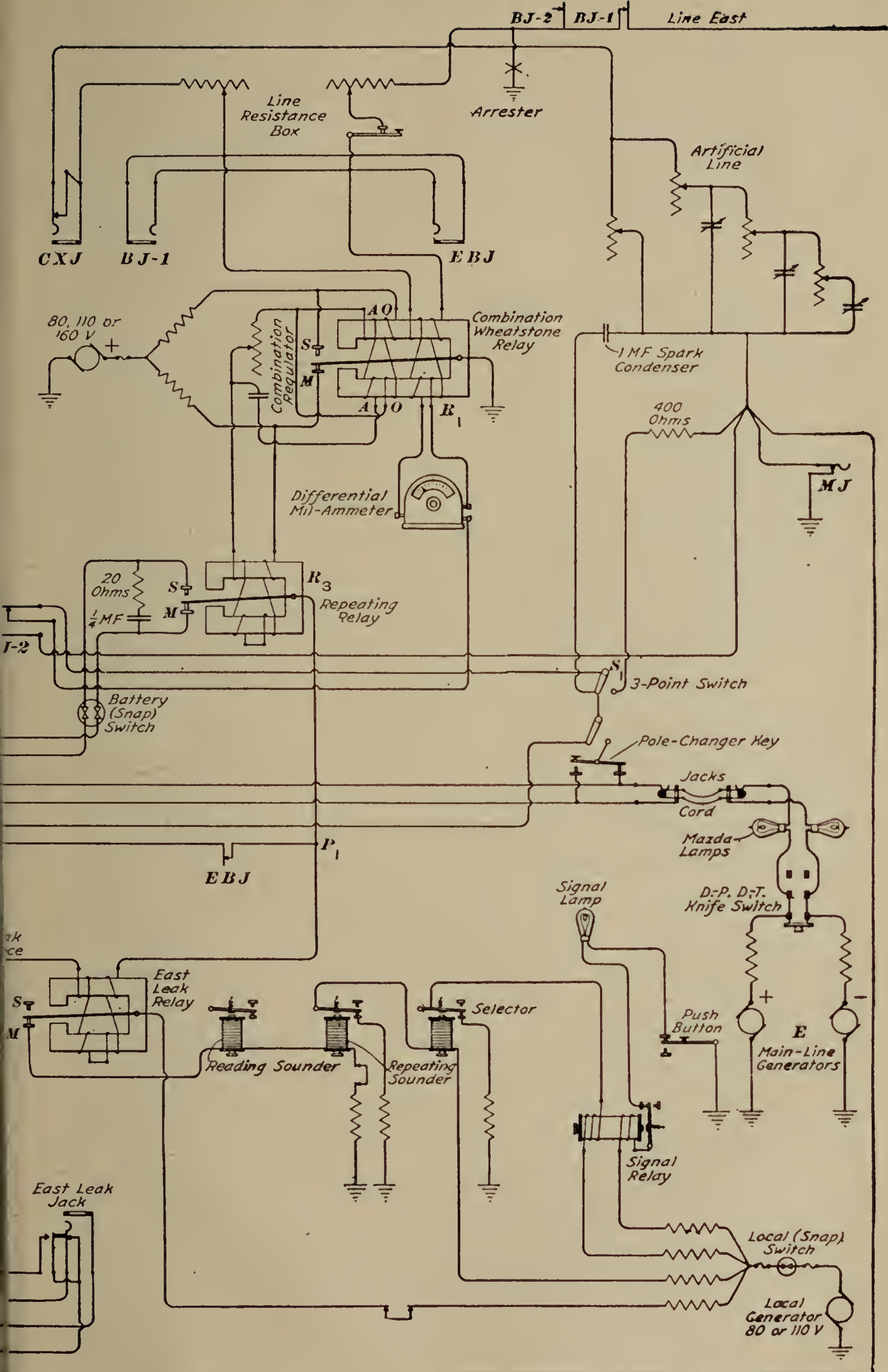
23. The complete connections of the main- and artificial-line circuits of the *bridge duplex-repeater sets* arranged for use with either telegraph or telephone lines is shown in Fig. 17. It is common practice, especially in complicated circuit drawings, not to loop one line over another where two wires do not make electrical contact, but to simply draw the lines across one another, care being taken to put a distinctive black dot where wires do make electrical contact, which method is followed in this figure. The two telephone composite switches, correspond to switches *CS* and *CS'* in Fig. 15 and are used to cut coils *w,* Fig. 17, and condensers *k* and *l* out of the circuit when telegraph lines are used and into the circuit when telephone lines are used.

When such sets are to be used with telegraph lines only, the two triple-pole, double-throw, telephone line switches, the generators *i* and *j,* the two telephone composite switches and the impedance coils *w* are eliminated and the telegraph line wires are connected directly to points *a* and *b,* the generators *g* are connected to points *c* and *d* on one pole-changer battery switch



BB 482B—2020

Fig. 1



BJ-2
BJ-1
Line East
Arrester
Line Resistance Box
Artificial Line
CXJ
BJ-1
EBJ
80, 110 or 160 V
Combination Regulator
Combination Wheatstone Relay
S
M
AO
A
O
R1
1 MF Spark Condenser
400 Ohms
MJ
Differential Mil-Ammeter
20 Ohms
1/4 MF
S
M
R3
Repeating Relay
J-2
Battery (Snap) Switch
S1
3-Point Switch
Pole-Changer Key
Jacks
Cord
Mazda Lamps
P1
EBJ
D.-P. D.-T. Knife Switch
Signal Lamp
East Leak Relay
S
M
Reading Sounder
Repeating Sounder
Selector
Push Button
E
Main-Line Generators
Signal Relay
East Leak Jack
Local (Snap) Switch
Local Generator 80 or 110 V

and the generators *h* to the points *e* and *f* on the other pole-changer battery switch. Otherwise the connections are the same as here shown. The 20-ohm lamp, or resistance, *m* and the $\frac{1}{4}$-microfarad condenser *n* are connected in series across the contacts of the direct repeating relay to reduce sparking at these points.

UNIVERSAL DUPLEX REPEATER

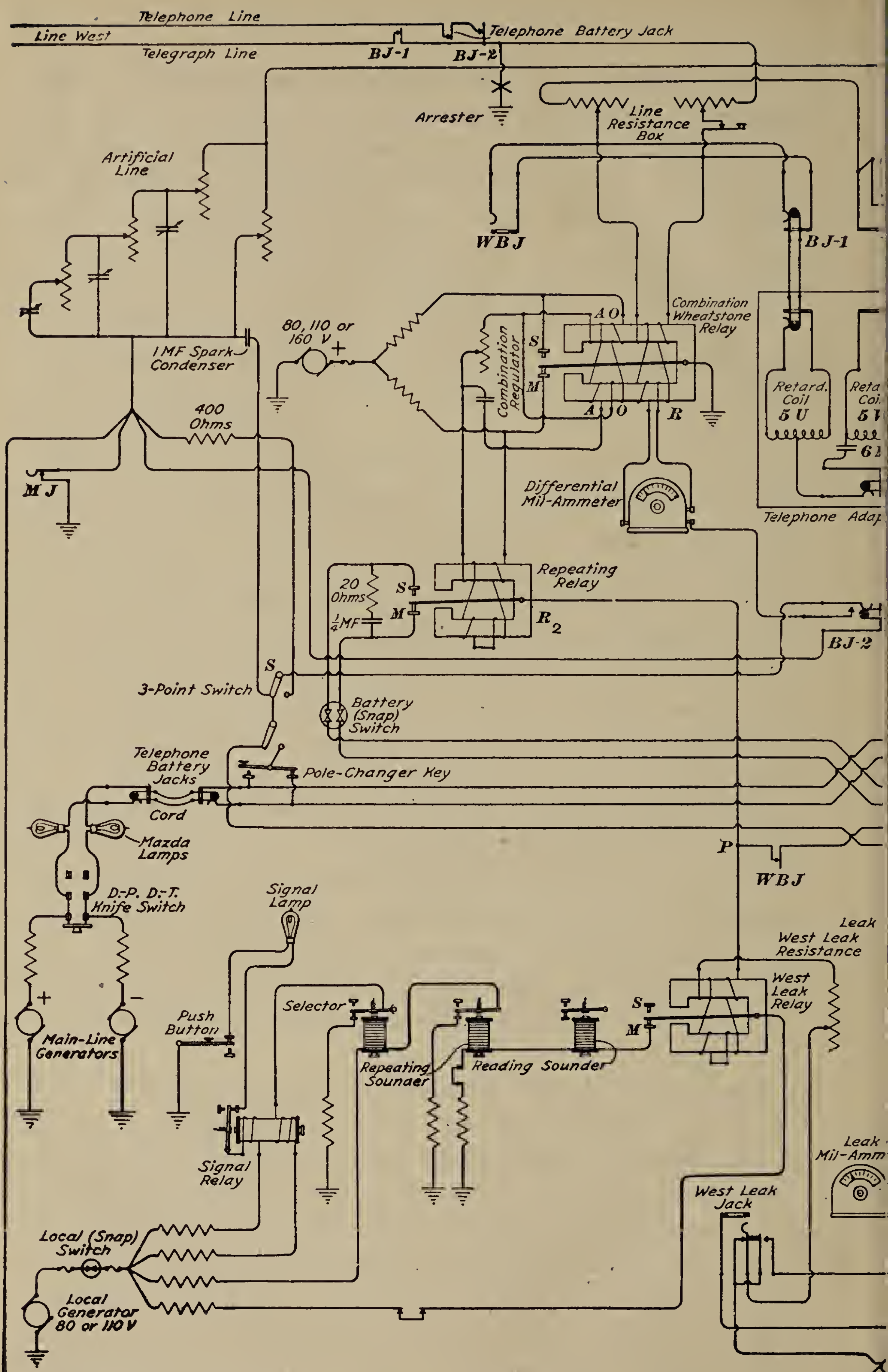
24. The *universal duplex repeater,* Fig. 18, is an assembly of duplex apparatus in one repeater unit by means of which signals may be repeated from one line to another, using, at will, the differential polar duplex; bridge polar duplex; differential polar duplex on one side repeating into a bridge polar duplex on the other; differential or bridge polar-duplex repetition with an intermediate station at the repeater point; two-terminal polar-duplex sets, either bridge or differential, and for operating duplex by any of these systems over a metallic circuit between terminal stations instead of over a single grounded line.

25. Main-Line Battery.—Motor generators supplying direct current at 80, 110, 160, or 240 volts, and storage batteries charged from local motor generators, or from commercial electric-power mains, are used, the same as in other terminal duplex sets. Where 110-volt or 220-volt commercial power is available at repeater stations, this is used instead of motor generators. Usually, the negative pole of the source of main-line current is connected to the closed, or marking, contact of the transmitting apparatus. By means of a double-pole, double-throw switch, Fig. 18, a higher or lower main-line potential may be applied to the set, the former when the line is long, and when wet weather prevails, and the latter for shorter lines, and when clear weather prevails. When the duplex is operated over wires simultaneously in use as a telephone circuit, minimum line voltage is employed on the telegraph side in order to avoid disturbances in the telephone circuit. For this purpose a pair of potential leads is brought to a telephone battery jack, and the voltage limited to the maximum allowed for transmission over simplexed circuits.

26. Differential Polar-Duplex Operation.—Fig. 18 shows a universal duplex repeater when arranged for differential polar-duplex operation. Signal impulses arriving on the western side actuate the combination Wheatstone relay *R*, which, by action of its armature in a local circuit, energizes a repeating relay R_2. The contacts of this relay are connected to the main-line generators *E*. Relay R_2 takes the place of a hand-operated pole changer, as movements of its armature will cause positive and negative impulses to pass through point *P*, pole-changer switch, 3-point switch S_1, jack *BJ-2*, the relay R_1, and from there to the eastern line.

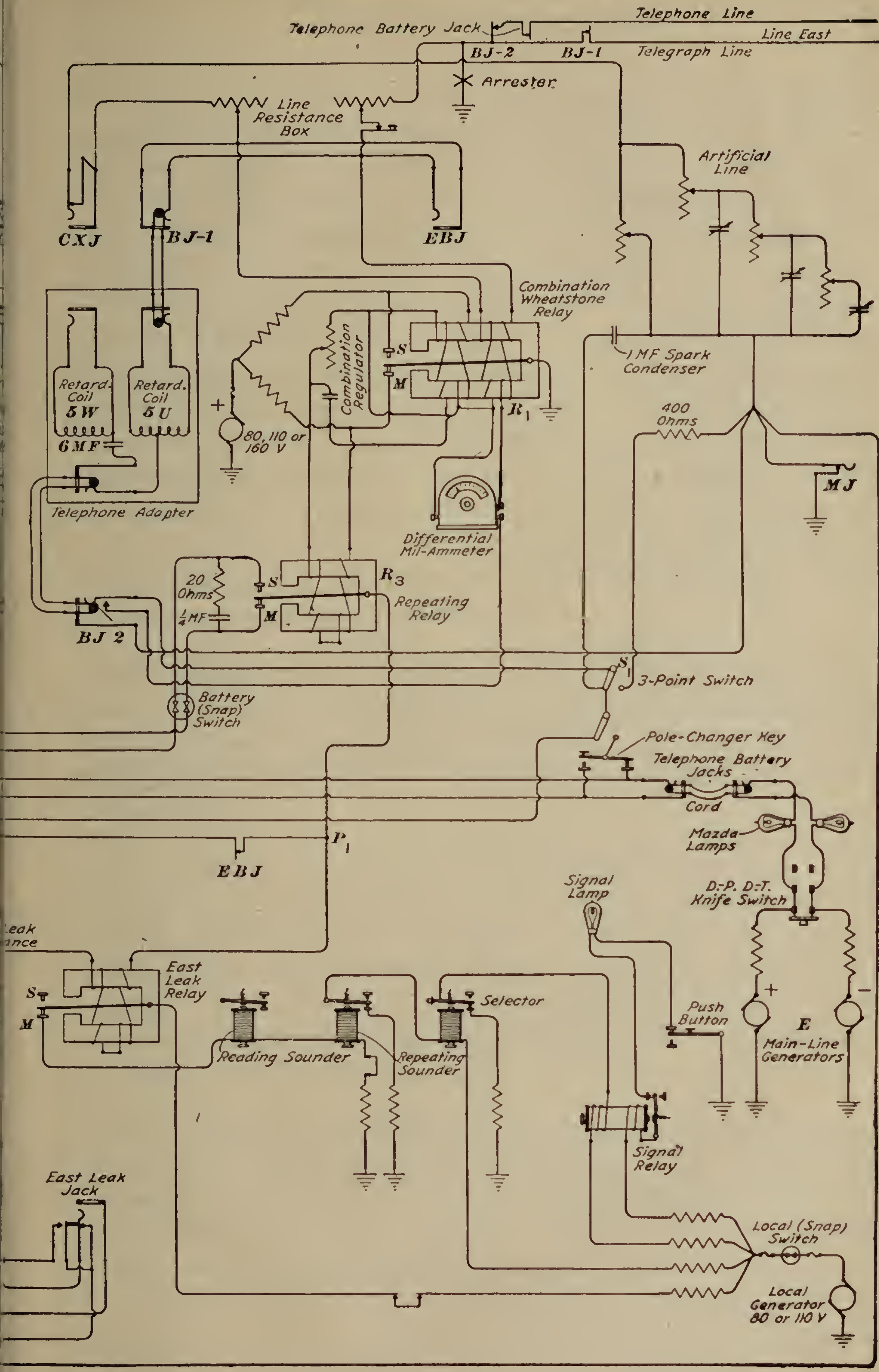
When the lever of the switch near the pole-changer key is moved to the right, the repeater is cut and transmission in either direction may be carried on by means of the pole-changer key. Leads extending from *P* and P_1 through the west and east leak relays and a high resistance to ground allow sufficient current to pass through these relays to operate them. The armature of the leak relay operates a local circuit containing a reading sounder and a repeating sounder. The reading sounder enables the repeater attendant to determine the character of the passing signals, while the armature of the repeating sounder operates a visual-signal circuit arrangement to draw the operator's attention to the fact that the line is in operation. The signal relay is locked in position each time impulses are sent over the line. It can be opened only by depressing a push button provided for that purpose. But this can be done only when the distant operator has ceased sending, as the repetition of signals would again energize and lock the relay, and light the signal lamp.

27. Bridge Duplex Operation.—The circuit shown in Fig. 19 is an adaptation of the universal duplex repeater for bridge duplex operation. The adapter unit, as shown in the illustration, consists of two retardation coils *5U* and *5W* one of them connected in series with a 6-microfarad condenser. The *5U* coil is used for bridge duplex operation and the *5W* coil for composited operation. The jacks marked *BJ-1* and *BJ-2* are provided on each set so that connection may be made by means of cords with the respective jacks of the adapter. Plugs inserted



Telephone Line
Line West
Telegraph Line
BJ-1
BJ-2
Telephone Battery Jack
Arrester
Line Resistance Box
Artificial Line
WBJ
BJ-1
Combination Wheatstone Relay
80, 110 or 160 V
1 MF Spark Condenser
Combination Regulator
S
M
A O
R
Retard. Coil 5 U
400 Ohms
MJ
Differential Mil-Ammeter
Telephone
Repeating Relay
20 Ohms
$\frac{1}{4}$MF
R2
BJ-2
S
3-Point Switch
Battery (Snap) Switch
Telephone Battery Jacks
Pole-Changer Key
Cord
Mazda Lamps
P
WBJ
D.-P. D.-T. Knife Switch
Signal Lamp
Leak
West Leak Resistance
West Leak Relay
Selector
Push Button
Main-Line Generators
Repeating Sounder
Reading Sounder
S
M
Signal Relay
Leak
West Leak Jack
Local (Snap) Switch
Local Generator 80 or 110 V

FIG.



Telephone Line
Telephone Battery Jack
Line East
BJ-2
BJ-1
Telegraph Line
Arrester
Line Resistance Box
Artificial Line
CXJ
BJ-1
EBJ
Combination Wheatstone Relay
Retard. Coil 5 W
Retard. Coil 5 U
6 MF
Combination Regulator
S
M
R1
80, 110 or 160 V
1 MF Spark Condenser
400 Ohms
MJ
Telephone Adapter
Differential Mil-Ammeter
20 Ohms
1/4 MF
R3
Repeating Relay
BJ 2
S1
3-Point Switch
Battery (Snap) Switch
Pole-Changer Key
Telephone Battery Jacks
Cord
Mazda Lamps
P1
EBJ
Signal Lamp
D-P. D-T. Knife Switch
East Leak Relay
Selector
Push Button
E
Main-Line Generators
Reading Sounder
Repeating Sounder
Signal Relay
East Leak Jack
Local (Snap) Switch
Local Generator 80 or 110 V

in jacks *BJ-1* and *BJ-2* remove the combination Wheatstone relay and differential milliammeter from the split and connection is made from the armature of the opposite repeating relay through the retardation coil *5U* directly to the bridge arms. The relay and the milliammeter are now bridged across the main and artifical line as in any other bridge duplex set.

The main-line battery is shown connected by a conducting cord to a telephone battery jack. The main-line battery used for simplex or composite operation is of lower potential than for differential working over telegraph lines. The telephone battery leads do not pass through a double-pole, double-throw switch and tungsten lamps as do the leads from the higher potentials used with the arrangement shown in Fig. 18. Each of the battery wires, Fig. 19, is, however, connected through a resistance lamp which glows brightly when a short circuit occurs. These lamps are placed near the dynamos.

28. Composite Working.—When the universal duplex repeater is used for telegraph operation over a composited line, that is for separate telegraph transmission over each wire of a telephone pair, the jack *CXJ*, Fig. 19, is connected to the retardation coil *5W*.

29. Differential and Bridge Circuits Joined.—When it is necessary to repeat from an ordinary telegraph line operated differential duplex into a telegraph circuit over a pair of telephone wires operated bridge duplex, the half of the universal repeater on the telephone side is arranged for bridge working and the half into which the single telegraph wire is connected is arranged for differential working.

30. Various Combinations.—This duplex repeater may be used for operation between two terminal stations without the repeater feature, that is, as an ordinary bridge or differential duplex between any two stations. To include at the repeater station a loop to a branch office, a special circuit adapter is used in which no connection is made with the negative line battery; instead, the closed, or making, contact of each pole changer is connected to the armature lever of the repeating relay on the

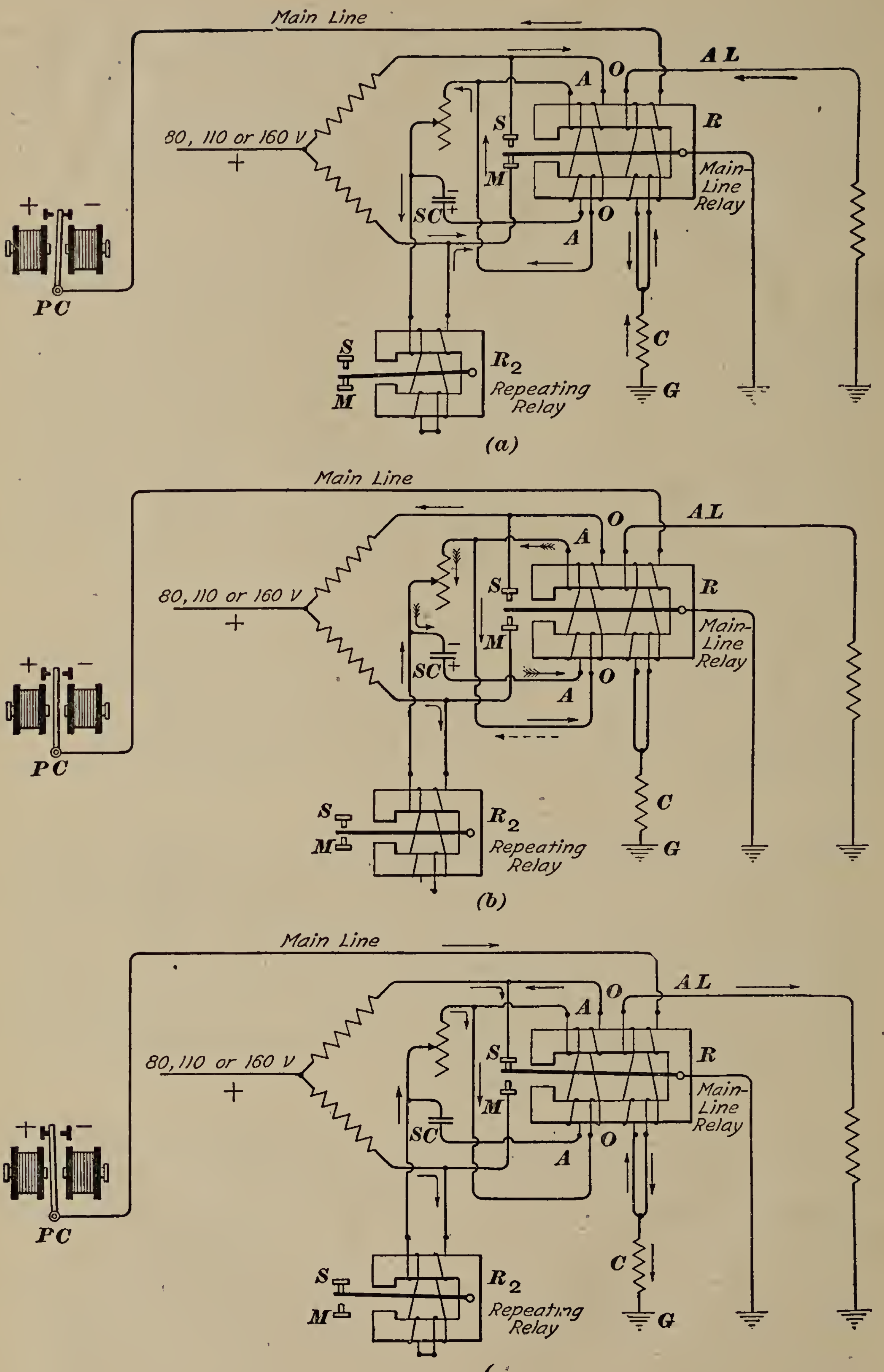

Main Line
AL
O
A
R
S
M
SC
80, 110 or 160 V
+
Main-Line Relay
PC
C
G
R2
Repeating Relay
(a)
Main Line
AL
O
A
R
S
M
SC
80, 110 or 160 V
+
Main-Line Relay
PC
C
G
R2
Repeating Relay
(b)
Main Line
AL
O
A
R
S
M
SC
80, 110 or 160 V
+
Main-Line Relay
PC
C
G
R2
Repeating Relay

FIG. 20

opposite half of the set. These adapter lugs are not shown in Figs. 18 and 19 but are made up simply of lugs mounted on dummy bars, removable and easily portable.

31. Duplex Over Metallic Circuit.—When it is necessary, due to aurora effects or to excessive inductive disturbances from neighboring electric power lines, to employ a two-wire circuit for telegraph duplex operation between two terminal offices, instead of a single wire grounded at each terminal, the second line wire is connected to the jack *MJ*, Fig. 18, at each end. With such an arrangement, the line will remain properly balanced, as both sides of the line are equally exposed to atmospheric disturbances.

32. Combination Wheatstone Relay.—The main-line receiving relays R and R_1, Figs. 18 and 19 are provided with two additional magnet windings for increasing the operating speed of the instrument. One extra winding $O–O$ is called the *opposing coil,* and the other winding $A–A$ is called the *accelerating coil.* In Fig. 20 (a), (b), and (c) the windings and connections of the combination Wheatstone relay, and the windings of the repeating relay, as used in the universal duplex repeater, are shown so that the action of the accelerating windings A, and the opposing windings O, may be studied. To simplify the wiring diagram, the home-transmitting apparatus is omitted. The resistance coil C represents the path from the split of the home set to the ground G.

33. Action of Extra Windings.—The arrows, Fig. 20 (a), show the direction of current through the various circuits. In view (a), the armature lever of the distant pole changer is in contact with the negative line battery; in view (b), the armature lever of the distant pole changer is in transit between its battery contacts; and in view (c), the armature is in contact with the positive-battery terminal.

In view (a), the direction of current in O is such that to a certain extent it neutralizes the magnetizing effect of the current in the main-line winding. The local-current strength, being much less than that of the main-line current, permits the latter to retain the tongue of the relay in contact with the marking contact *M*. The condenser *SC* receives a charge due to the fall of potential across the active portion of the resistance. The resistance and the condenser *SC* in Fig. 20 (*a*), (*b*), and (*c*) form a single unit of apparatus. In Figs. 18 and 19 this unit is marked *combination regulator*.

At the instant the pole changer at the distant station reverses the line current, there is a brief period during which the pole-changer armature lever is not in contact with either battery contact. During this time, the current in the main-line winding of relay *R* is greatly reduced; hence, the current in the winding *O* can now establish a magnetic flux, which will start the relay armature toward its spacing contact without being forced to wait until the pole-changer lever at the distant station reaches the opposite battery contact.

When the armature lever of the distant pole changer, view (*b*), is between its battery contacts, the home condenser *SC* discharges through the coil *A* causing the relay armature to move toward its spacing contact *S*. The current of discharge after passing through the winding *A*, divides, part of the current passes through the resistance and part through the winding *O*, thence through the windings of the repeating relay R_2 in a direction to cause the armature of that relay to move toward its spacing contact *S*. The dotted arrow below the wire from *O* indicates the direction in which the current from the local generator that passes through winding *O* tends to travel before the armature has separated from contact *M*. This current is overcome by the current of discharge, the direction of which is represented by the plain arrow.

Fig. 20 (*c*) indicates the current conditions in the main and local circuits when the armature of the distant pole changer has reached its back, or positive-battery, contact. When the pole-changer armature lever leaves the positive-battery contact, the *turnover* currents will again actuate the relays, but in the reverse direction since the currents are reversed. In the combination regulator, the resistance is adjustable at 5,500, 7,250, or 11,000 ohms, and the condenser *SC* has a capacity of 2 microfarads.

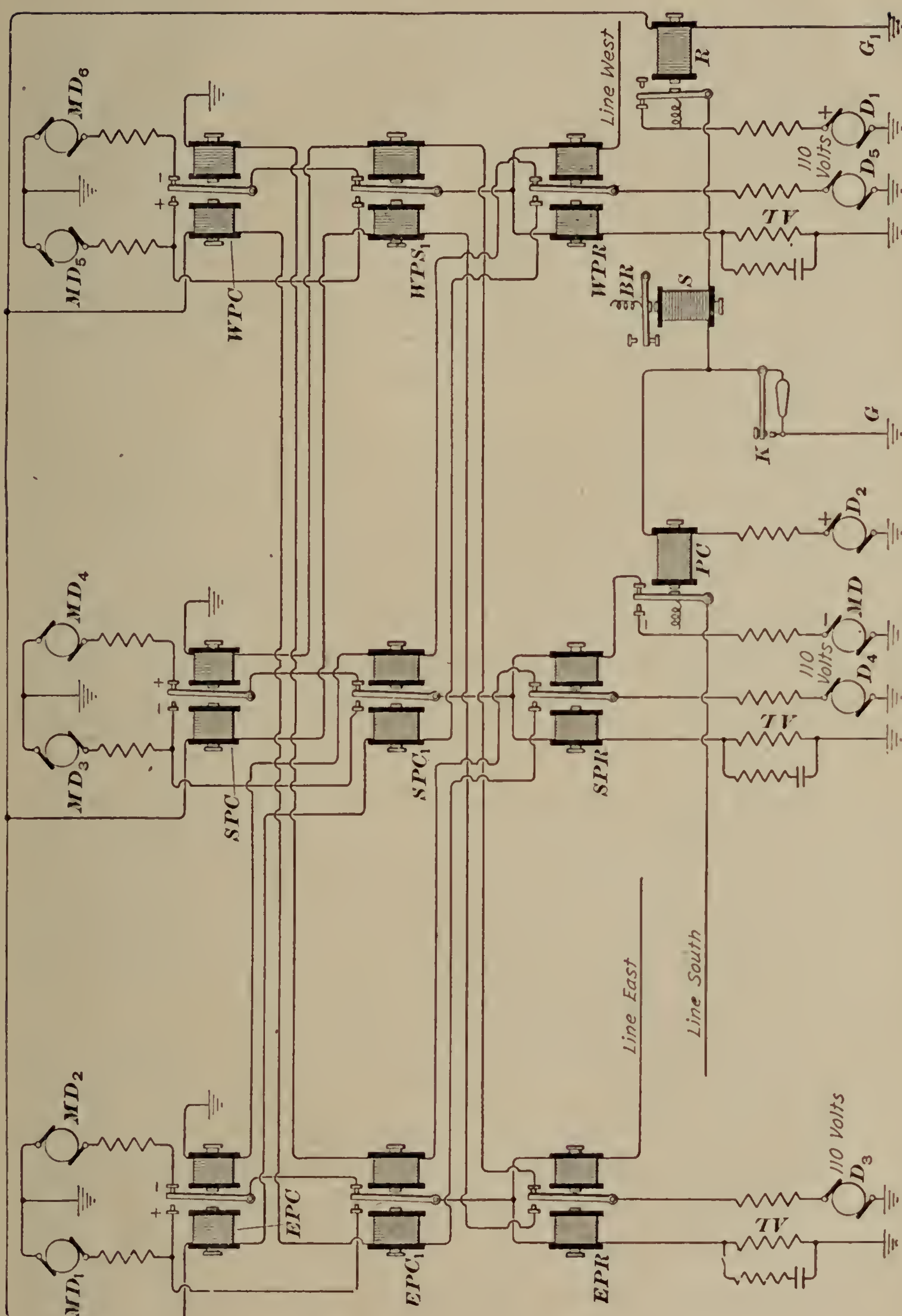

MD₆
MD₅
WPC
WPS₁
WPR
Line West
R
G₁
D₁
D₅
110 Volts
TV
BR
S
G
K
D₂
PC
MD
D₄
110 Volts
TV
MD₄
MD₃
SPC
SPC₁
SPR
Line East
Line South
MD₂
MD₁
EPC
EPC₁
EPR
110 Volts
D₃
TV

FIG. 21

THREE-WAY DUPLEX REPEATER

34. Purpose of Three-Way Repeater.—In terminal telegraph offices, it is often found necessary to connect two or three duplexed lines together in such a way that a branch office may also have control of the circuits. This arrangement is desirable in the transmission of newspaper telegraph matter where high speeds of operation are maintained. Although in many such instances transmission is carried in one direction only over each of the three lines, the nature of the service, however, is such that it is advisable to employ polar duplex rather than ordinary single lines.

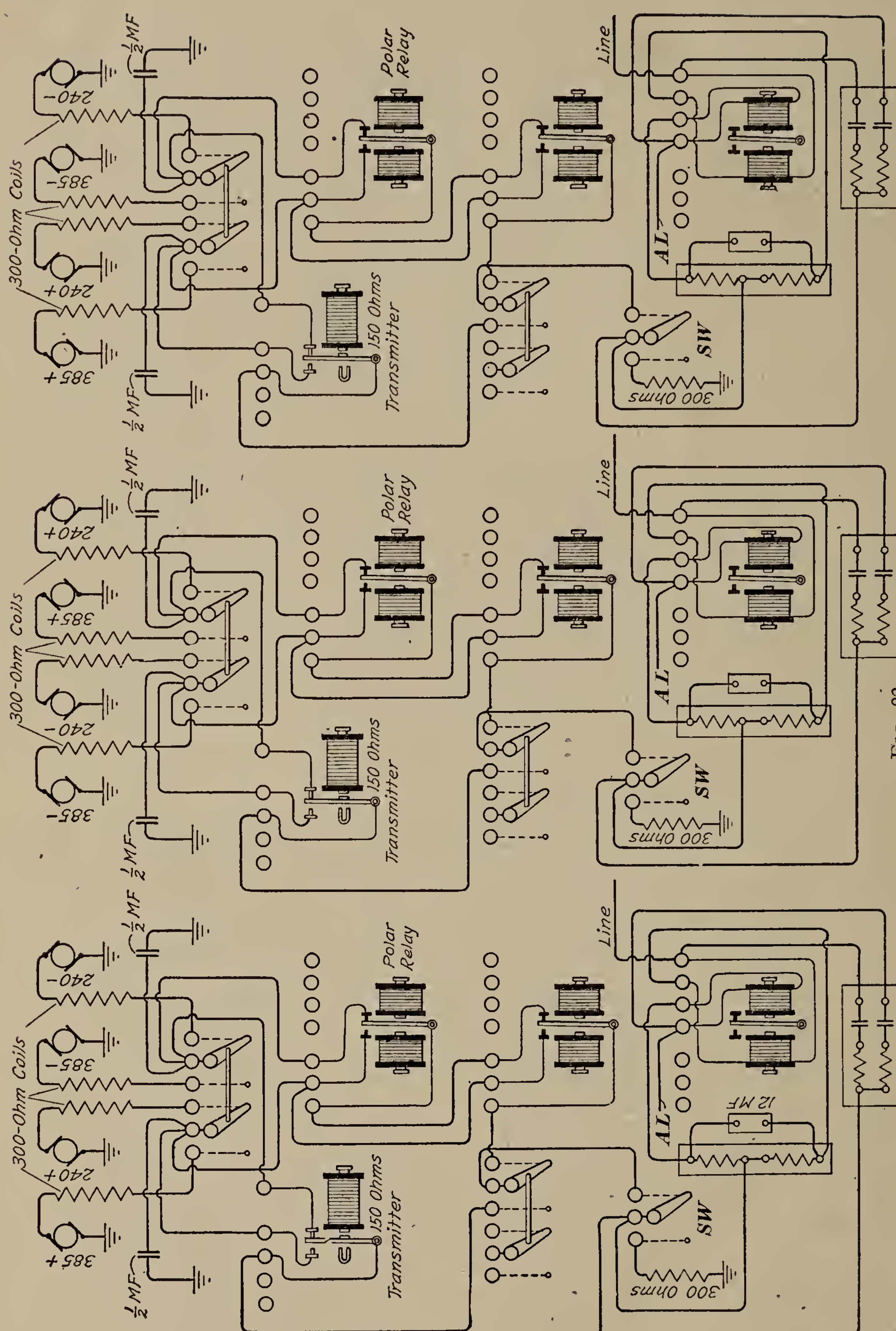
Fig. 21 shows an arrangement of repeater apparatus in which any one of the terminal stations or the branch station may send and the remaining stations receive the message. Any one of the receiving operators, including the branch operator, may interrupt transmission for the sake of repetition. The advantage of this system is that no half repeater or house-circuit repeater is used at the repeater station to relay the signals to the branch office.

35. Operation.—Each main line terminating at the repeater station is provided with two sets of pole changers and one polar relay. The letters *E, S,* and *W* preceding the letters *PC* and *PR* signify east, south, and west. The main-line dynamos *MD* to MD'_6 supply current for line transmission, and dynamos D_1 to D_5 supply current for local circuits.

With the armature levers of the main-line pole changers and of the main-line relays in the position shown in Fig. 21, the circuit through relay *R* and the common wire of the left-hand coils of pole changers *EPC, SPC,* and *WPC* is open and the armature of *R* is against its back stop. The circuit is opened since the left-hand stops of the main-line relays do not now touch the relay armatures. Dynamo D_1 has a closed path to ground *G* through the sounder *S* and the key *K*. Dynamo D_2 has a closed path through the pole changer *PC* and key *K*. The armature of *PC* is against its front stop and a positive current is being sent out on line south by dynamo MD_4. Line east and line west are connected to the negative terminals of dynamo MD_2 and MD_6 respectively.

Under these circuit conditions, assume that the branch operator opens his key K thus removing the ground connection for the positive terminals of dynamos D_1 and D_2. Dynamos D_1 and D_2 are in a complete circuit but their electromotive forces oppose each other and the sounder S and the pole changer PC are de-energized. The armature of pole changer PC makes contact with its back stop and a negative current impulse is applied to the line south. The circuit through the line windings of SPR is open at the front contact of PC and the current in the artificial-line windings of relay SPR will cause the armature to move to its left-hand stop. This action allows current from dynamo D_4 to pass through the left-hand magnets of pole changers EPC_1 and WPC. The armature of EPC_1 is now connected to the positive terminal of dynamo MD_1 and a positive current impulse is sent out over line east. The armature of WPC is now in contact with the positive terminal of dynamo MD_5 and a positive current impulse is sent out over line west. The circuit of relay R is completed through the left-hand magnets of WPC and EPC_1 and the left-hand stop of relay SPR. The armature of R is drawn against its front stop.

When the branch operator closes key K, pole changer PC is energized by the current from dynamo D_2. The armature of PC moves to its front stop, a positive current impulse is sent out over the line south from dynamo MD_4. The armature of relay SPR is moved into contact with its right-hand stop and the right-hand magnet coils of EPC_1 and WPC are energized by current from dynamo D_4. The armatures of EPC_1 and WPC are forced against their right-hand stops. A negative current impulse is, therefore, sent out over each of the lines east and west. The circuit through relay R was opened when the armature of SPR separated from its left-hand stop. The armature of relay R moves against its back stop and sounder S is energized by current from dynamo D_1. It should be noted that when the key K is closed, the currents in lines east, south, and west are in directions the reverse of those when key K is open. The signals that are sent out by the operator at the branch station BR are



½ MF
240-
385-
240+
385+
300-Ohm Coils
Polar Relay
150 Ohms
Transmitter
Line
AL
SW
300 ohms
12 MF

Fig. 22

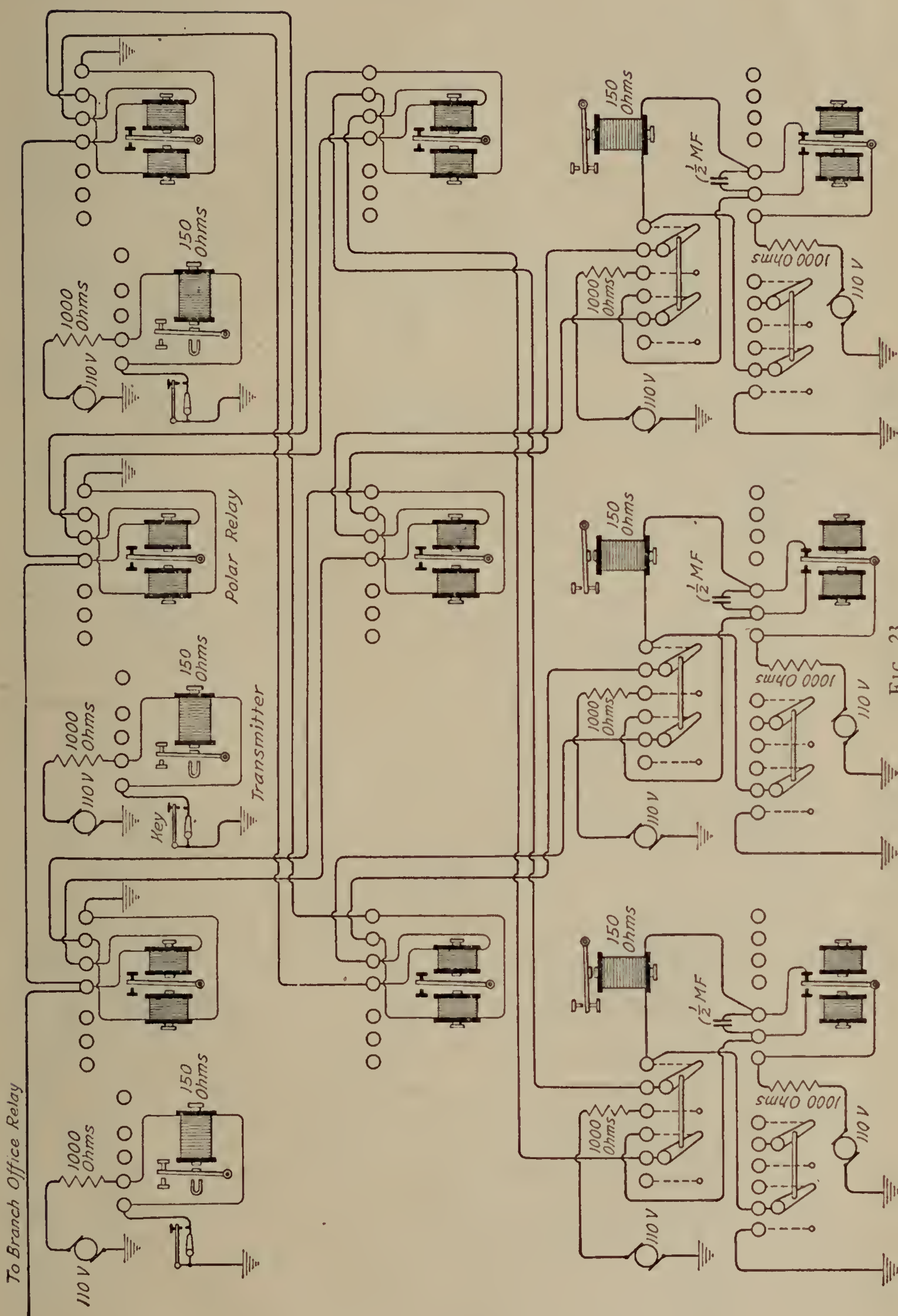

To Branch Office Relay
1000 Ohms
150 Ohms
110 V
Polar Relay
Transmitter
Key
1/2 MF

Fig. 23

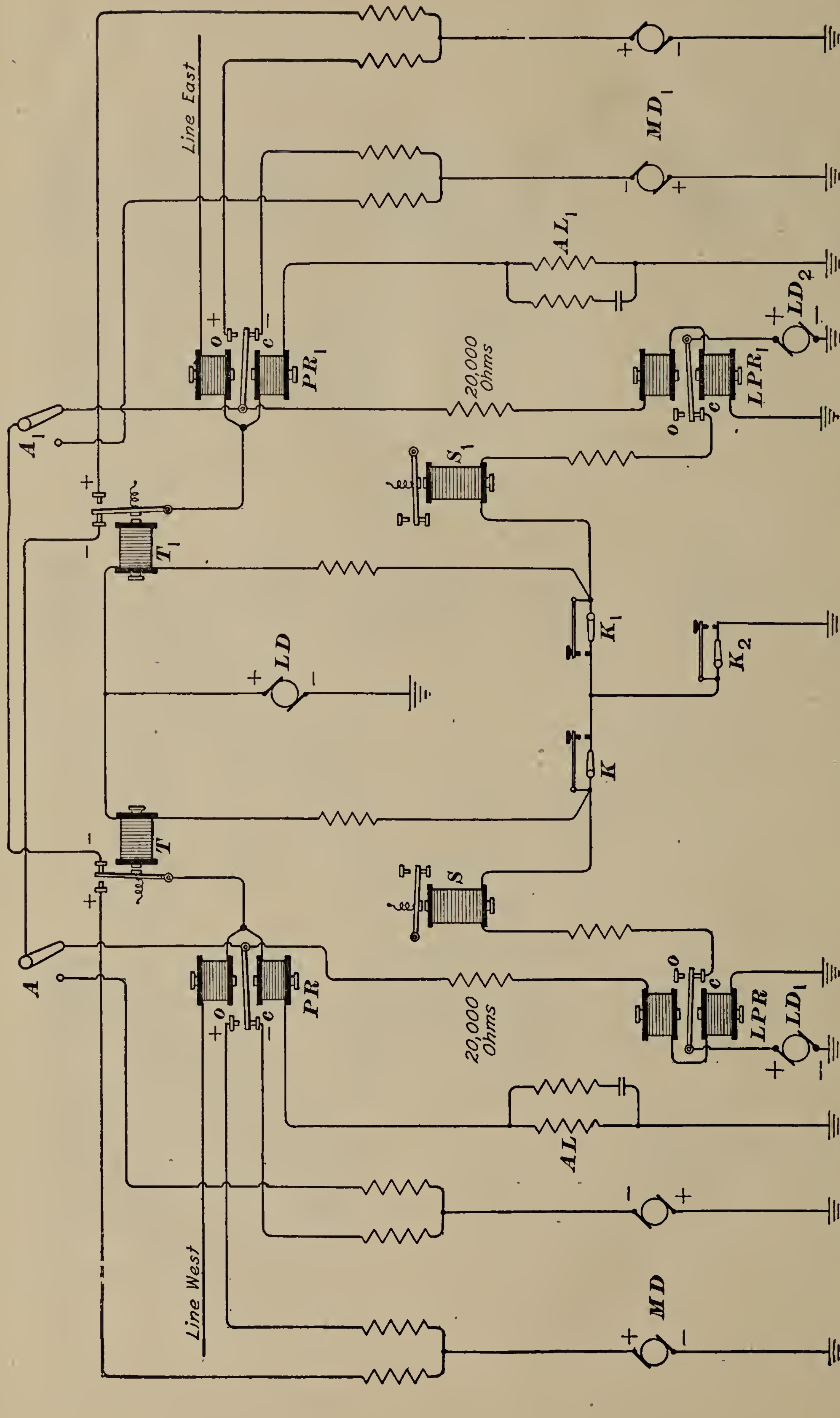

Line East
MD1
AL1
LD2
PR1
20,000 Ohms
LPR1
A1
S1
T1
K1
K2
LD
K
T
S
A
PR
20,000 Ohms
LPR
LD1
AL
MD
Line West

Fig. 24

repeated into the duplex systems of the east, south and west main lines.

If the operator at the distant end of line east opens his key, the armature of *EPR* moves to the left-hand stop and current from dynamo D_3 passes through the left-hand magnets of WPC_1 and *SPC* and through the relay *R*. A positive current impulse is sent out over line west, a negative current impulse is sent out over line south, the armature of relay *R* is drawn against its front stop, and the sounder *S* is deenergized. The message from line east is repeated into the line south, the line west, and into the branch office.

36. Main-Line and Local-Current Wiring Diagrams.—Fig. 22 shows the instrument binding-post, main-line connections of a three-way polar duplex repeater used by the Postal Telegraph-Cable Company. The duplex wiring is similar to that described in a previous Section. Fig. 23 shows the local circuits of the instruments. In general this repeater operates in a manner similar to that explained in connection with Fig. 21.

DIRECT-POINT DUPLEX REPEATER

37. Features of Direct-Point Repeater.—Fig. 24 shows an arrangement of apparatus for direct repeating from one duplex line to another duplex line. This system is used extensively by the Postal Telegraph-Cable Company. The polar relays *PR* and PR_1 act as receiving instruments and also as pole changers. The local circuits, including the pieces of apparatus of the branch office, enable the branch-office attendant to copy the passing signals in either or both directions, and, by means of keys *K*, K_1, and K_2 to transmit messages in either direction or in both directions. The closed contact points and the armature levers of the transmitters *T* and T_1 in the positions shown, are connected in series with the line west and in series with the line east, respectively. The back contacts of transmitters *T* and T_1 are connected to the positive terminals of the dynamos *MD* and MD_1 which terminals are also connected to the open contacts of the polar relays *PR* and PR_1. The closed contacts of the relays

PR and PR_1 are connected to the negative terminals of the dynamos.

38. Operation of Direct-Point Repeater.—Assume that the distant western operator is sending through the repeater station to the distant eastern station. The distant western operator opens his key, the armature lever of the polar relay PR moves to open position o and a positive current impulse is sent through switch A and out over the line east. The current for the line east is supplied from the positive terminal of dynamo MD. When the distant western operator closes his key, the armature lever of the polar relay PR moves to closed position c and a negative current impulse is sent through switch A and out over line east. The current is supplied from the negative terminal of dynamo MD. In a similar manner, line east can repeat into line west through polar relay PR_1 and switch A_1.

The incoming signals from both directions are repeated to the branch office through 20,000-ohm leak circuits to ground by way of series-connected polar relays LPR and LPR_1. The sounders S or S_1 are energized by current from the local dynamos LD_1 or LD_2 when contact c of polar relays LPR or LPR_1 is active. When transmission is from west to east only, sounder S at the branch office serves as the receiving sounder. When transmission is from east to west only, sounder S_1 serves as the receiving sounder. When signals are being transmitted over the two duplex lines in both directions simultaneously, sounder S responds to signals passing from the west to the east and sounder S_1 responds to signals passing from the east to the west.

39. Assume that the branch office wishes to communicate with either one or both of the distant main-line operators. The keys at both distant stations are to be closed so that the armature levers of both polar relays are against their closed contacts, and the front contacts of transmitters T and T_1 are connected to the negative terminals of the main dynamos. Under these conditions, the switches A and A_1 remain in their normal right-hand position. If the line west is to be used, key K is operated. When key K is opened, thus removing the ground connection, dynamos LD and LD_1 oppose each other. Transmitter T is deenergized and its armature lever moves against its positive contact, thus sending a positive current impulse over the line west. When key K is closed, the ground connection is restored, transmitter T is energized and a negative current impulse is sent out on line west. Sounder S is energized from LD_1 when key K

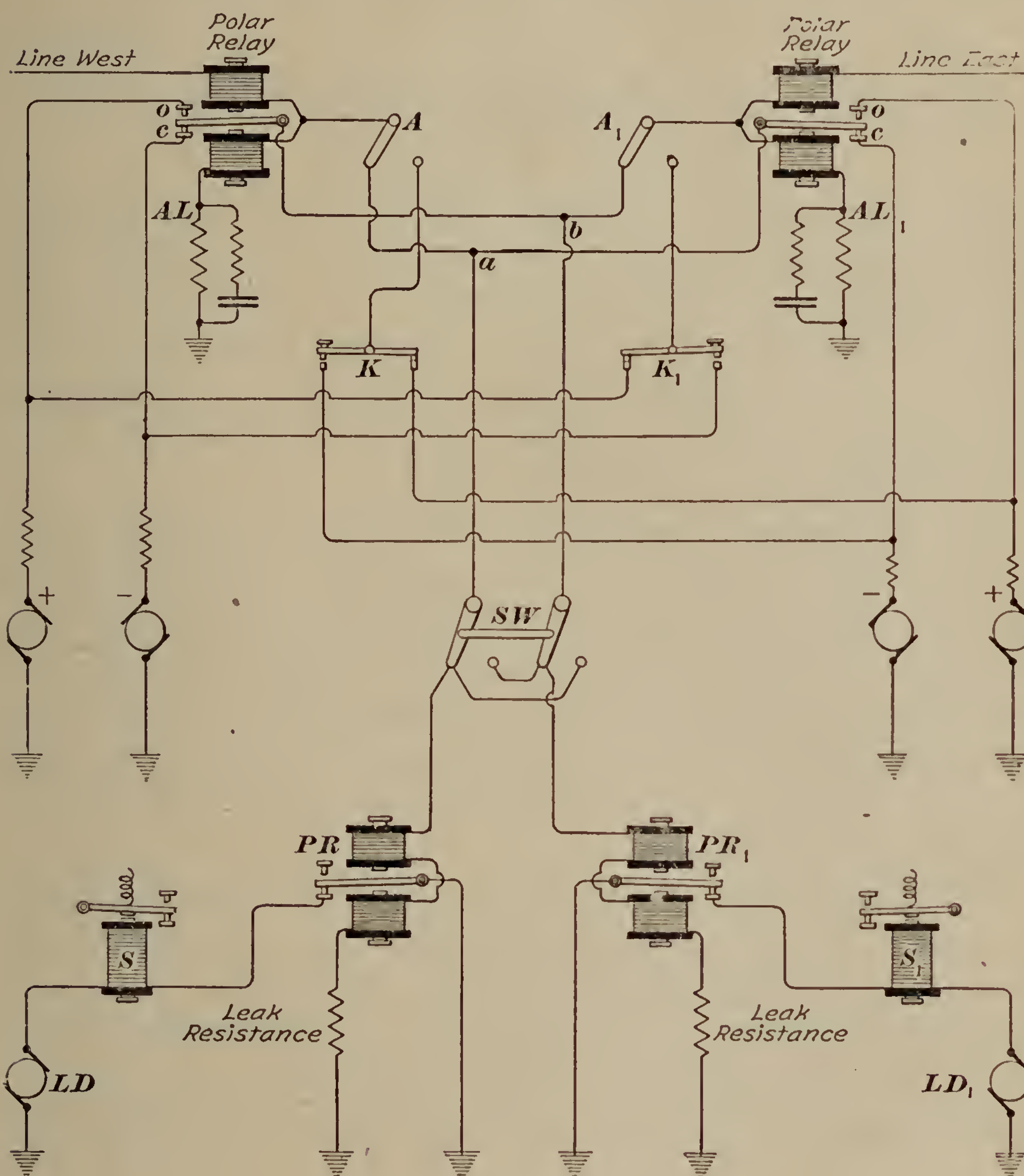


Fig. 25

is closed and it now acts as a sending sounder. When key K_1 is operated, similar action occurs on the line east and when key K_2 is operated, messages are transmitted west and east.

40. When switch levers A and A_1 are thrown to the left, the front contacts of T and T_1 are connected to the negative terminals of the main dynamos. The branch-office operator may communicate with either or both of the distant main-line operators, but the main-line operators cannot now communicate directly with each other through the repeater station. The distant operators can break in by opening their pole-changer keys.

HIGH-SPEED AUTOMATIC, DIFFERENTIAL-DUPLEX REPEATER

41. Fig. 25 shows a repeater system used by the Western Union Telegraph Company. It is a direct-point repeater with high-resistance, leak-circuit receiving taps extending from points *a* and *b*. This circuit arrangement is used principally for repeating high-speed automatic or printing-telegraph current impulses. The purpose of the leak receiving circuits is to provide observation facilities for repeater attendants.

The two levers of switch *SW* are joined so that the levers move in unison to the left or right as desired. Polar relay *PR* may be replaced by a high-speed Wheatstone tape recorder or an undulator for observing the character of signals passing over the circuit. When the switch *SW* has its levers to the left as shown, the relay *PR* receives signals from the line east. With the switch-levers to the right, the signals coming from the line west are recorded by *PR*.

The pole-changer key *K* and K_1 and the associated switches *A* and A_1 enable the repeater attendant to communicate with the distant terminal offices east or west. If the repeater operator wishes to signal the western operator, he turns switch *A* to the right and operates key *K*. If the communication to the east is desired, switch A_1 is thrown to the right and key K_1 is operated.